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Modelling Operational Command Structures using ORGAHEAD

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ABSTRACT

Computational modelling has been used successfully to explore the influence of organisation structure on organisation performance. Results from these explorations have helped to develop organisation science theories. This report describes the method and results of a series of experiments that were conducted to assess the suitability of ORGAHEAD, a computational modelling tool, in analysing operational command structures.

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Executive Summary

Effective military decisions are a characteristic of effective command. But effective command can depend on the type of command structure that is in place. That is the arrangement of the elements of command: the people and the resources. Unfortunately, command structures can be complex and, using traditional methods, difficult to analyse. One approach that overcomes some of these difficulties is computational modelling: a computer simulation in which the static and dynamic elements of organisational structures can be represented using agents. The characteristics of, and relationships between, the agents are usually embedded in the software. ORGAHEAD, developed at the Carnegie Mellon University (CMU), is an example of a computational model that was designed to explore and compare the decision-making performance of organisational structures. It has a built in simulated annealing algorithm that can propose, and switch between, different structures; a feature that is useful for exploring the effects of structural change on performance. And it has agents that are endowed, in a limited sense, with cognitive abilities: they can learn from experience, and they can classify patterns.

This report describes a series of experiments that were conducted to assess the suitability of ORGAHEAD in supporting the analysis of ADF operational command structures. It starts by describing how parts of previous experiments conducted at the CMU were reproduced and used to validate ORGAHEAD functionality, and then it describes a series of experiments that explored the way in which agents, representing the elements of specific operational command structures, could learn, classify, and make decisions. The specific command structures used to illustrate the approach were drawn from historically significant military operations.

A small number of features of ORGAHEAD were investigated, but the results show that it had only limited utility when used to contrast and compare the characteristics of models of command structures of moderate size. Five limitations came out of the experiments which should be taken into account when evaluating the validity of the results and/or using ORGAHEAD in the future. Firstly, the directions and the types of communication flows that can be modelled in ORGAHEAD are restricted. Sideways and downwards communications flows between the agents are not allowed, and although some indirect feedback from the highest level is accommodated, the main direction of communication flow is upwards. Secondly, the different types of relationships that can exist within a command structure such as authority, accountability, friendship, and mentoring, just to mention a few, are not accommodated. These types of relationships generally take second place to direct upwards reporting. Thirdly, because the actual command structures that were represented in the experiments were complex, it was difficult to accurately capture them, particularly at the intermediate levels. Unfortunately, the historical records used were only partially suitable, so to be pragmatic, some minor(?) structural modifications were made. As the number of organisation levels that can be accommodated in the

model is limited, structures were truncated. Fourthly, the performance of some structures were found to be quite sensitive to changing task relationships. In these cases the alteration of just a few agent-task links significantly altered the performance. Finally, ORGAHEAD is a software research tool, that during the course of the investigation, was being upgraded. Changes to the software, to introduce new features and to make corrections, were regular. As a result, early versions of the software did not always perform as they should. In the future, ORGAHEAD software version stability and robustness need to be firmly established before embarking on any extensive investigations.

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Ashley Cook (retired Technical Officer) completed a radio apprenticeship in 1966, he then moved to Woomera for 14 years and worked in a trials support role. In 1980 he returned to Salisbury and worked in the Trials Branch and the Combat Systems Division of WSRL, where he was engaged in development work associated with timing and audio recording techniques for field trials and exercises. Prior to his retirement, Ashley supported investigations into organisational concepts using computational modelling tools.

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Abbreviations

ADF	Australian Defence Force
ADO	Australian Defence Organisation
AOP	Allied Operations in the Pacific Area, 1944-45
C2D	Command and Control Division
CASOS	Centre for Computational Analysis of Social and Organisational Systems
CC2D	Chief Command and Control Division
CDF	Chief of the Defence Force
CEO	Chief Executive Officer
CJOPS	Chief of Joint Operations
CMU	Carnegie Mellon University
DJTF	Deployable Joint Task Force
DSTO	Defence Science Technology Organisation
GCINCW	German Command Arrangements – Normandy, 1944
GUI	Graphical User Interface
INTERFET	International Force East Timor
JCA	Joint Command Analysis
MHz	Mega Hertz
ODS	Operation Desert Storm, 1991
ORGAHEAD	Organisation Look Ahead
OSET	Operation Stabilise – East Timor, 1999-2000
OVERLORD	Allied Command Arrangements – Normandy, 1944
PAEF	Possible Australian Expeditionary Force, beyond 2002
PC	Personal Computer
RAM	Random Access Memory
RLJCA	Research Leader Joint Command Analysis
SEAC	South East Asia Command, 1945
SOP	Standard Operating Procedure
SWPA	South West Pacific Area
T317	Task Force 317, British Operations in the South Atlantic, 1982
VCDF	Vice Chief of the Defence Force

1. Introduction

1.1 Context

A major part of the research carried out within Joint Command Analysis (JCA) Branch has sought to identify ways of investigating Australian Defence Force (ADF) command arrangements, particularly joint command. The research has been directed towards how organisational science methods and various types of modelling tools can be used to analyse command and control structures. It has also concentrated on the identification of the organisational factors that make command and control effective, efficient and able to adapt to the changing nature of modern military conflict.

1.2 Purpose of the report

This report discusses the computational modelling tool ORGAHEAD[1] and provides examples that show how it might assist the analysis of command and control structures. The report discusses how ORGAHEAD can be used to explore the relationship between command structure and organisational performance[2], and it describes experiments that show how it was used to investigate actual operational command structures. In the main, the structures referred to are the operational command structures associated with historically significant high-intensity conventional-warfare military operations. The report also discusses the suitability and limitations of ORGAHEAD and proposes how it might be used in future studies.

The analysis approach described is just one of several that are being developed in conjunction with other investigative approaches, such as social network methods and narrative techniques. The results from this work will help to provide a better understanding of how computational modelling might be used to assist the analysis of the Australian joint operational headquarters. Reference is made to a possible command structure for an Australian expeditionary force.

1.3 Report outline

Section 1 provides the context and purpose for the report as well as an outline of the contents.

Section 2 provides the background material for the following sections. It discusses the role of operational command structures and the changing nature of military conflict.

Section 3 discusses modelling. It describes the role and importance of models and how they can be selected and used to describe operational command structures. Also

[1] The word ORGAHEAD is a shortening of ORGanisation-look-AHEAD. A description of ORGAHEAD is given later in the report.
[2] Performance in this report is defined as decision-making efficiency, which is explained later.

discussed are measures that can be used to compare command structures, decision-making, and ways of modelling decision-making. ORGAHEAD is described, along with an outline of the method used for conducting the experiments[3].

Section 4 describes the investigation. The equipment set-up for the experiments is described, and as a way of providing at least a partial validation of ORGAHEAD, some of the experimental results, previously obtained by the Carnegie Mellon University (CMU), are reproduced. Three experiments that used a selection of military command structures are described along with the difficulties experienced in trying to compare the command structures. Model validation is also discussed.

Section 5 to 8 present the conclusions drawn from the discussion, a list of recommendations, acknowledgements, and a list of references.

Appendix A illustrates the current command arrangements for the ADF. Appendix B outlines the operational flow of ORGAHEAD, and includes details of simulated annealing and the Metropolis algorithm. Appendix C illustrates the command structures used in the experiments. The reference material used to create the structures is also included. Appendix D details the parameter lists (excluding default values) for the three experiments. It also provides (in table form) the data used to support the graphs.

2. Background

The defence of Australia and its interests by the ADF is a complex undertaking. Complex because there are a large number of different types of tasks that need to be performed. In performing these tasks the ADF brings individuals and resources together. It combines the specialised skills of military and civilian personnel with a variety of equipment. The responsibility for completing the tasks is shared by the many different work-groups that exist within the ADF, while the coordination of the work-groups is the responsibility of the operational[4] commanders.

2.1 Operational command structures

The structure of an organisation is formed by the network of relationships that exist between the different elements (individuals, resources[5] and tasks). There are relationships between individuals (e.g., supervising, mentoring, friendship, etc.),

[3] The experiments referred to in this report are computer simulations. They could be more correctly described as virtual experiments.
[4] Operational command is the highest level of command within the ADF and includes the Chief of Joint Operations who reports directly to the Chief of the Defence Force.
[5] As well as materials, resources include intangibles such as information, knowledge, skill, and experience.

between resources[6], and between tasks[7]. There are also relationships between individuals and resources (e.g., who uses what resources), between individuals and tasks (e.g., who does what task), and between resources and tasks (e.g., what resource is used for what task).

Although the ADF operational command structure is complex, for the purpose of simplifying the analysis, the structure can be considered to be made up of components. But, of course, the different ways in which the overall structure is considered to be decomposed, or partitioned, into components will result in different representative networks. The networks can be homogeneous, where the elements are all of the same type, or they can be heterogeneous, where different types of elements are represented. The structures that represent the relationships between individuals are referred to as social networks, but within each type of social network there can be sub-networks. Also, social networks can be divided into formal and informal categories. Formal social networks can be used to represent the agreed reporting or authority or supervision arrangements within an organisation – as is sometimes depicted on organisational structure charts, while the informal social networks can be used to map the less well defined types of relationships such as trust, mentoring, or friendship.

An important coordinating network within the ADF is the operational command structure. This network is responsible for the overall planning and direction of defence operations. Within the ADF this high-level command structure (see Appendix A) is realised in the individuals (and resources) that make up the various military components, e.g. Land, Maritime, Special Operations, etc. To be effective there needs to be a great deal of interaction and communication between each of the different components.

2.2 The changing nature of conflict

The security environment that Australia finds its self in is continually changing. As a result of this, the types of conflict that the ADF is likely to be asked to respond to in the future are likely to be without precedent. Recent world events such as terrorism and cyber-warfare are good examples of the asymmetrical nature of newer types of military conflict that can be added to the list of conflict types that Australia is likely to be confronted with (Army 1998). Also, not all of the changes to the ADF are a result of the changing external security environment. Changes within the ADF are also due to an ongoing need to become more effective and efficient.

2.3 Changes to the ADF operational command arrangements

To meet the changing nature of the external and internal defence environment it is necessary for commanders to be able to effectively deal with the changing nature of the

[6] Replacement - the substitution of one resource for another.
[7] Precedence - the order in which the tasks are performed.

tasks they are responsible for. Different tasks require different skill-sets and resources. To be efficient, commanders need to be able to adapt to changing task requirements in a timely manner. The inability to adapt could mean the loss of a battle.

In 2001, the Australian government announced (Reith 2001) its intention to build a new operational defence headquarters and to integrate and collocate (where appropriate), single service functions, making greater use of joint service arrangements, indicates the government's intent to improve defence's command capability. This improvement will come about through the more effective coordination of different tasks, increased collaboration, improved decision making, and more accurate and timely communication of the commander's awareness and intent. The collocation of the headquarters aims to facilitate the streamlining and rationalisation of functions so that there will be an increase in the overall efficiency of the ADF operational command arrangements.

To support this collocation, operational command arrangements were reviewed and a set of simpler, more direct, command arrangements for ADF operations was introduced (Cosgrove 2004). These command arrangements are illustrated in Appendix A. The Wilson Review (2005) has since further revised these arrangements.

3. Modelling

Modelling is an effective technique that can be used to represent and assist the analysis of organisations, in particular command structures. This section discusses the purpose and importance of modelling with a particular emphasis given to computational modelling and to ORGAHEAD, a computational modelling tool, which is briefly described. An example, using a simple command structure, illustrates how ORGAHEAD might be applied.

3.1 Modelling concepts

3.1.1 Purpose of models

A model of a system is a simplified representation of the system that can be used to aid understanding and communicate ideas about the system. A useful model includes important parts of the system and leaves out the unnecessary details (Kaposi and Myers 1994). Models are used to alleviate unnecessary complexity, but during the process of creating a model (in particular, identifying essential elements and removing unnecessary detail) there is the risk that some important elements will be discarded. So checks are needed to make sure that the model remains representative. This checking process is called validation. During validation, comparisons are made between features (physical characteristics or behaviours) of the model and the system being modelled and the consequence of any differences is evaluated.

3.1.2 A systems view of an operational command structure

Operational command structures[8] are complex open systems. They are complex because they consist of a large number of different types of entities that interact with each other and the external environment in a variety of ways. These entities include: individuals[9], tasks, processes, and technologies. Operational command structures are open because of the way they interact and influence those elements that are part of their external environment such as: the tactical military forces associated with the component services, allied and coalition forces, branches of government, the commercial sector, and other non-government organisations[10]. Given such variety, the comprehensive analysis of an operational command structure usually requires a range of modelling approaches. That is, no single method, model, or view, is generally sufficient to adequately describe them. For the analysis of these systems to be rigorous, and their description comprehensive, a multidisciplinary approach is usually required (Yates and Burke 2000). As each model only gives a partial description, one approach that has been proposed for building a more comprehensive description is to overlay a number of different models (Yates and Burke 2000). Of particular interest are those methods and modelling tools that can help to develop a better understanding of operational command structures and the influence that variations to the elements that comprise those structures may have on organisational performance. One particular approach that is examined more fully in this report is that of computational modelling.

3.1.3 Computational modelling

Using the computational modelling method, the static and dynamic characteristics of a command structure are represented in a computer simulation as numbers or symbols, sometimes referred to as computational agents. Real world entities, such as individuals, are represented using these computational agents. These agents usually have (limited) cognitive abilities and they can be configured in the model to form (usually simple) relationships with other agents. For most computational modelling tools, the extent of the complexity of the command structure that can be represented is usually moderate. That is, a moderate number of agents can be represented, and a moderate level of detail can be assigned to each agent (which determines the agent's cognitive abilities). The main problem being that too many agents and/or too many details can result in a significant increase in the time required to run the simulation. The simulation algorithms can be computationally complex and so the speed of execution depends on the power of the computer. Simulation runs can take from a few seconds to several hours, or even days (sometimes weeks). Simulations usually produce lists of data which require a considerable amount of additional statistical and/or graphical interpretation.

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[8] The structure of an operational command is determined by the way the elements have been arranged.
[9] Individuals also refers to groups of individuals.
[10] The concept of operational command is not restricted to the confines of a military headquarters.

3.1.4 The importance of decision making

The individuals within an operational command structure have many types of tasks to perform. These tasks include: receiving guidance from and providing information to higher strategic or political authorities, planning military campaigns, monitoring and controlling longer-term operations, and allocating resources. These tasks result in extensive amounts of information flowing in and out of the operational command structure. In fact, information is the main commodity, e.g., intelligence reports, tasking orders, advice to government. Also, the individuals working within an operational command structure use information to produce more information.

An important part of the information-producing activity is decision-making. Decisions are made at all levels throughout an operational command structure and they help set the direction for courses of action. For example, a situation awareness task relies on: the ability of individuals (and in some cases intelligent agents, e.g., smart sensors) to correctly identify the state of the external environment, make decisions about courses of action, decide who gets what resources, and resolve conflicts that arise. One tool[11] that is being used to explore structural factors that influence decision-making within an operational command structure is ORGAHEAD.

3.2 ORGAHEAD

ORGAHEAD is one of a series of organisational analysis tools developed by the Centre for Computational Analysis of Social and Organisational Systems (CASOS) at the CMU. The development of ORGAHEAD is ongoing and it is being used at the CASOS to conduct experiments to help researchers to understand organisations and develop organisational theories. The following brief description of ORGAHEAD is based on material obtained from the CASOS web site.

3.2.1 Description

ORGAHEAD is a text based computational modelling tool originally written in C. It can be used to model moderately complex organisational structures, and through the use of an inbuilt simulated annealing algorithm is suitable for representing and investigating organisation change and adaptation. The name ORGAHEAD comes from 'organisation-look-ahead', which encapsulates the underlying concept behind its operation, namely, searching for and replacing a given organisational structure with one that is more suitable. ORGAHEAD was originally written for UNIX operating systems, but now can run with Microsoft Windows. The source code, as well as the configuration control, for ORGAHEAD remains the property of the CASOS. With permission, it is freely available from the CASOS website.

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[11] Other types of organisation modelling tools, such as CONSTRUCT and DYCORP, have also been developed by CMU.

ORGAHEAD is not a commercial software product. It was created at the CASOS to assist organisation science researchers. The software development documentation and the support mechanisms are appropriate for this purpose. Although it has found application in some other domains, its use so far has been mainly by researchers and students, who also have been responsible for its maintenance. Software upgrades have been ongoing, and even at the time that this report was being prepared, modifications and extensions to the program were being introduced.

ORGAHEAD can be used to model how internal and external changes influence decision-making efficiency[12][13] within an organisation. Individuals, tasks, and reporting structures can be represented and the reporting structures can be altered as can the assignment of individuals to different tasks. Also, the individuals within an organisation can be added, moved, and removed.

The structure of an organisation reflects the way its components (individuals, resources, and tasks) relate to each other. ORGAHEAD facilitates the modelling of the components and their relationships. In ORGAHEAD, agents are used to represent individuals and there are four types (levels): analysts, managers, CEOs, and a president (a later version of the program extends this number of levels). It also accommodates, in a limited way, the static and dynamic representation of the cognitive and decision-making processes of each individual and the organisation as a whole.

In ORGAHEAD, the structure is defined by the reporting arrangements (see Figure 1). For the purposes of this example these organisational reporting arrangements can be formal or informal as no distinction is made between them. The analysts, who are at the lowest level, work only on tasks and report to either managers or CEOs. The managers receive inputs from analysts and report to the CEOs who, in turn, report to the president. The reporting (information flow) structure is strictly in the (upwards) direction - analyst to president. Downwards reporting and sideways reporting is not allowed. Not all levels need to be filled, but the maximum number of agents that can exist at any level is 15[14], except in the case of the president, where only one is allowed.

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[12] Decision-making efficiency is a performance measure. It is the ratio of the number of correct decisions made compared to the total number of decisions made, usually expressed as a percentage.

[13] There are two types of efficiency measures used in ORGAHEAD, absolute efficiency and relative efficiency. Absolute efficiency is expressed as a percentage and refers to the number of correct decisions made for all the tasks in a given simulation. Relative efficiency is also expressed as a percentage, but it refers to the number of correct decisions made during a cyclic efficiency check period, which consists of a preset number of tasks. In this report, unless suggested otherwise, efficiency refers to relative efficiency.

[14] This upper limit can be exceeded in later versions of the software.

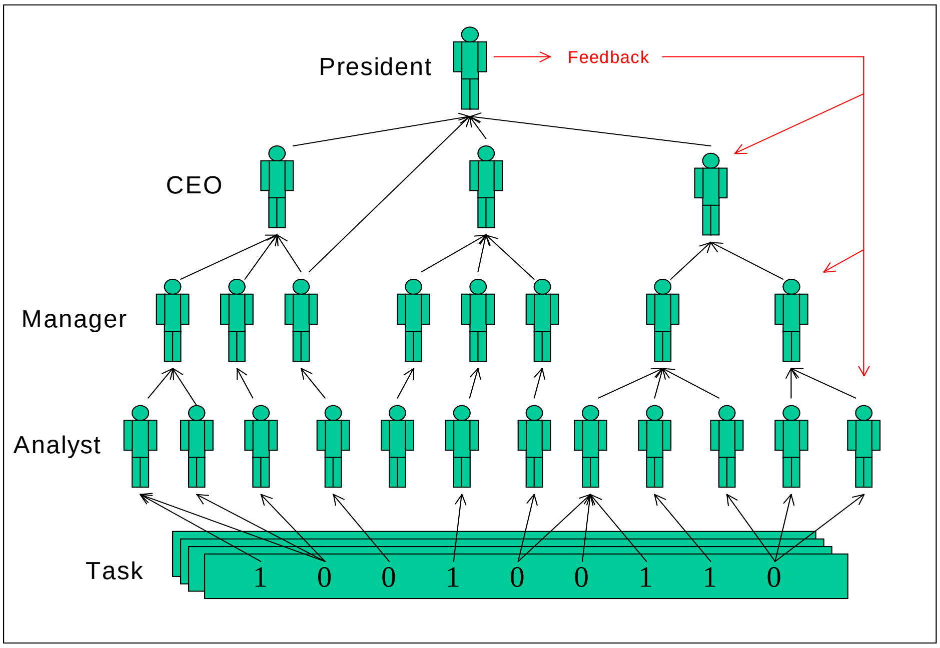

Figure1 Organisational Structure represented in ORGAHEAD

The type of task performed is that of classification. The task information is represented by a bit-string (ones and zeros), where each bit within the string represents an element, or fact, associated with a task[15]. The complexity of the task is proportional to the number of bits represented. In Figure 1 there are nine bits represented, and each bit can have two[16] values (one or zero). The maximum number of task bits that can be represented in a bit-string is 18. For the experiments described below the task complexity was left at the default value, nine.

For each task, the objective of the agents (and the organisation) is to correctly classify the bit string. Within each task, each analyst, manager, and CEO, is given a classification sub-task in which they only have access to a few of the bits of the information for the overall task. Regardless of the number of input bits any agent receives, it only produces one output bit (1 or 0). The sub-task classification results produced at one level become the inputs to the next higher level and the final (highest-level) classification is that produced by the president who represents the organisation's classification. If there is no president the final decision for the organisation becomes the responsibility of the CEOs, who use a majority voting scheme to obtain a result. If the vote is tied the result is randomly chosen.

In determining organisational efficiency, the classification made by the organisation is compared to a previously determined classification for that bit string. There are

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[15] For example, the classification (friend or foe status) of an unidentified aircraft based on observed characteristics such as speed, direction, height, radar emissions, etc.
[16] ORGAHEAD can also represent task bits that have three values (ternary).

various, and in some cases complex, ways in which the actual classifications can be made, but a simple method is just to compare the total number of ones with the total number of zeros. If there are more ones than zeros, the result is classified as ‘belonging’ (represented by a 1); if there are more zeros than ones, the result is classified as ‘not belonging’ (represented by a 0); if the number of ones is the same as the number of zeros, the result is classified as ‘uncertain’ (in this case the agent guesses and the result is represented by either a 1 or a 0).

These ideas are represented in Figure 1 which shows a simplified military structure in which ORGAHEAD is used to represent a watch-keeper chain of command. In this case, the watch-keepers at the lowest level (analysts) receive inputs from the environment about friendly or hostile activities. These inputs, or facts, are represented in the form of ones and zeros. The job of each watch-keeper is to decide if an observed activity is friendly or hostile. Figure 1 shows that no agent at any level in the chain of command has access to all of the task information, so the decisions made by each agent are based on limited amounts of task information. The environment places bounds on the ability of agents to make rational decisions (March and Simon 1958). Even though each watch-keeper has access to only some of the task information, they still need to make a recommendation (either a one or a zero) that they can then pass up to their superiors (managers), who in turn assess what they have received before passing their recommendations further up the chain to the commander (President). Based on these recommendations, the commander will make the final classification about the friendly or hostile nature of the observed activities.

An important feature of ORGAHEAD is its ability to automatically generate organisational structures. Alternatively, the user may specify particular structures that are to be used. Typically, each organisational structure is subjected to a sequence of different tasks (using randomly chosen bit-strings), and for each task the organisation makes a classification. The classifications made at the different levels of the structure by the individual agents (agents, managers and CEOs) are also logged and are used internally within ORGAHEAD to determine individual efficiencies.

Two mechanisms are used within ORGAHEAD to improve efficiency: individual (or experiential) learning, and structural learning. In the first mechanism, the agents can be programmed to learn to improve their efficiencies. Using feedback, the agents’ responses can be compared to the ‘correct’ responses (that is, the responses that would result if the agents had access to all of the task information instead of just a portion of it). Over time the agents can learn to recognise and remember the patterns of the ‘correct’ responses and to adjust the way they respond in the future to similar patterns so that they improve their efficiencies and, in so doing, the efficiency of the organisation. Alternatively, the agents can be programmed to act as majority classifiers, where their outputs are based solely on an assessment of the current inputs. In this case agent memory is switched off and the agents ignore previously seen patterns and any feedback they received relating to how well they performed. Another option allows the agents to be programmed to ignore all input stimuli and feedback and just guess. The second mechanism that ORGAHEAD uses to improve organisational efficiency is structural learning. With structural learning the organisation can automatically propose a change to the structure, that is, agents or links can be added or deleted. After the change the new efficiency is determined and compared to the pre-change efficiency. If there is an improvement the new structure is adopted, if not, the old structure is retained. The automatically generated structures are randomly produced using Monte-Carlo simulations. The underlying structural learning mechanism used within ORGAHEAD to search for and retain an improved structure uses a simulated annealing optimisation algorithm. Appendix B contains a brief description of simulated annealing. It also contains an outline of the ORGAHEAD program flow, which is based on the organisational life cycle diagram shown in the report by Carley and Svoboda (Carley and Svoboda 1996).

3.2.2 Experimental method using ORGAHEAD

The following general method was adopted for the ORGAHEAD experiments. Initially, the appropriate ORGAHEAD parameters were identified. Following this, the range of the parameters was determined and the fixed parameters were set. The experiments (simulations) were then run and the resulting data was collected and converted into a form that was suitable for display and further analysis.

3.2.3 Input parameters

ORGAHEAD allows the manual set-up and adjustment[17] of more than 220 simulation parameters and the details of specific organisational structures. Prior to each experiment, the input parameters were set from the command line interface[18]. Most of the parameters were set to their default values. Broadly, the following parameters were controlled:

- Number of simulations;
- Annealing parameters;
- Number, size and types of tasks;
- Number and type of agents;
- Amount of training;
- Number of efficiency checks;
- Number of times memory is reset;
- Structure of the organisation;
- Adding, changing, and removing agents;
- Adding, changing, and deleting connections; and
- Printing.

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[17] Most of the parameters were set to their default values. See Appendix D for a list of variations to the default parameter settings.
[18] Later versions of ORGAHEAD come with a more elaborate menu driven graphical user interface (GUI).

3.3 Microsoft Excel

Depending on switch settings, the amount of data generated during an ORGAHEAD experiment can be copious. It depends on the number of simulations and the number of tasks executed during each simulation. It includes: organisational structure before and after changes, efficiency of the organisation and the agents, annealing statistics, resources used, the experience of the agents, and other task details. To manage and interpret this data it is usually necessary to convert the output files (usually lists of characters) into a form that is suitable for further analysis. Much of the data that were produced during the simulations required additional graphical interpretation and/or statistical interpretation. In these cases the data were converted into a form that was suitable for interpretation using Microsoft EXCEL.

4. Investigation

This section describes the method and results obtained from the ORGAHEAD investigation.

4.1 Investigation outline

The aim of the investigation was to determine the suitability and scope of application of the ORGAHEAD in analysing the efficiency of military operational command structures. The question that was asked was, Is ORGAHEAD suitable for helping analysts to reason about military operational command structures, and can it assist analysts in advising military strategists and planners in optimising or adapting a particular military structure to suit different types of military conflict? To answer this question the investigation was carried out in three phases: initialisation, validation, and evaluation.

The aim of the initialisation phase was to install and set-up ORGAHEAD. This phase allowed the different features and the operational characteristics of the ORGAHEAD program such as the user interface, printing and graphing facilities, memory usage, program execution times, hardware platform requirements, and software robustness, to be configured and examined.

The validation phase aimed to establish that, within its design constraints, ORGAHEAD was suitable for investigating the efficiency of organisational structures. To carry out this phase, parts of the experiments previously conducted at the CASOS were used to guide the approach. Although the general methods used by CASOS are outlined in published papers, the exact details of the conditions and input parameter values were not available, so it was not possible to duplicate their results. In any case, the statistical nature of the method and making use of Monte-Carlo simulations based on current time seeds, would have made the results obtained during the CASOS experiments difficult, if not impossible, to duplicate. So the aim of this part of the investigation was to provide sufficient confidence in the method and the general consistency of the results obtained in order to continue on to the next phase.

In the evaluation phase, the efficiencies of operational command structures drawn from recent military conflicts were evaluated. A structure from a recent conflict involving Australians was included, along with a structure that represents a potential set of ADF operational command arrangements that could be used in a future conflict. Because of the statistical nature of the simulation results, each structure was evaluated several times and the results were averaged over the total number of simulations. The efficiencies of the structures for both experiential learning and structural learning were assessed. Also, the effect of increasing the number of structural links between agents, and between agents and tasks, was evaluated.

4.2 Installation, set-up, and general operational features (phase 1)

The general aim of this installation and set-up phase was to:

- Determine the hardware requirements;
- Get the software working;
- Observe the default operational characteristics;
- Determine the form of the output;
- Observe the effects of varying the input parameters;
- Determine the amount of memory required;
- Measure the time required to run a simulation; and
- Determine the graphing requirements.

A Microsoft Windows version (ver. 2.1.3) of the ORGAHEAD executable was supplied (floppy disks), without obligation, by CASOS; source code was not available. The software was installed on a PC fitted with a Pentium 4 processor (clock speed 500MHz) and 256MB of RAM. The operating system used was Windows 2000. Some software reliability problems were identified and reported to the CASOS, as were some of the experiences from using ORGAHEAD during the investigation. But the software development did not remain static and new versions were released that introduced new features and fixed software bugs.

The documentation supplied with the software consisted of copies of papers and reports that have been published in various international journals (see references for relevant articles). The software help files included a list of the ORGAHEAD commands, parameters, and general details. No user manual, product specification, or detailed operational description, was available, but additional information was available from the CASOS website (see Appendix B). Good support in overcoming software and operational difficulties was provided by the CASOS personnel working (see acknowledgements section). The latest version of ORGAHEAD (not the one used for these experiments), which includes an improved user interface and associated support documentation and examples of argument files that can be used for testing, can be downloaded from the CASOS website.

To exercise the hardware and software an initial set of arguments (mainly defaults) from the parameter list was determined and several exploratory simulations were conducted. Sufficient success was achieved in this part of the investigation to allow progress to the next phase.

4.3 Validation (phase 2)

The aim of this phase was to become familiar with the operational characteristics and limitations of ORGAHEAD by repeating parts of the appropriate CASOS experiments. Unfortunately, the actual setup data used in the CASOS experiments was not readily available, so the results could not be fully reproduced.

4.3.1 The CASOS experiments

Two CASOS experiments were considered. The first was based on the method described in the paper titled 'Modelling Organisation Adaptation as a Simulated Annealing Process' (Carley and Svoboda 1996). The second experiment was based on the paper 'Organisations and Constraint-Based Adaptation' (Carley 1997). Both experiments exercised the experiential learning (agent memory) and structural learning (simulated annealing) features of ORGAHEAD.

In both of these experiments 1000 organisational structures were randomly generated by ORGAHEAD. A graph that shows the results obtained for each of the 1000 simulations is shown in Figure 2. Each dot represents the results of one simulation. Here, the efficiency (performance) is the dependent variable, while organisational size and span of control are the independent variables. Colours are used to represent five efficiency ranges. Size refers to the total number of agents used in each simulation. The agents that represent the analysis, managers, and CEOs are randomly distributed across the different levels. Span of control refers to the average of the number of agents supervised per supervisor in each simulation. Because it is possible for two or more organisational structures with different efficiencies to be created using the same number of agents and the same span of control, some of the lower performing structures are masked by higher performing structures. This results in less than 1000 organisational structures being represented in the figure.

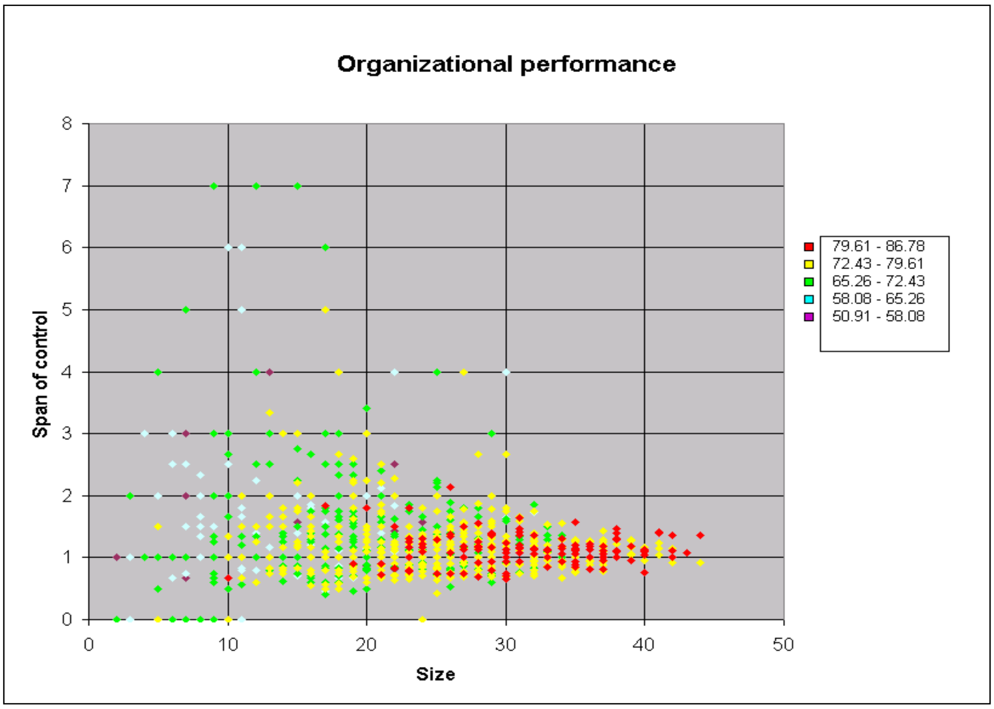

Figure 2 Efficiency (Performance) vs. Size & Span of Control

The graph shows a larger number of points (organisational structures) in the lower region. The algorithm for randomly generating the structures was not available, so the exact explanation for this is uncertain. But because the parameter that controls the maximum span of control was set to 7, a generally lower span of control could be expected. Also, another feature of the graph (red cluster) shows a concentration of higher efficiencies for those structures that have a larger number of agents and a low span of control. This needs to be investigated further, but agents with an odd number of inputs (and they are in the majority) never have to guess. An agent acting as a majority classifier and observing a single input value (either one or zero) does not alter the value before passing it up the command chain. Similarly, agents with three, five, seven, etc, inputs will never be uncertain about what value to pass up. For agents with an even number of inputs (two, four, six, etc), there will be combinations of input data that will necessitate guessing. But in these cases the likelihood of having to guess decreases as the number of inputs increases: for two inputs the likelihood of having to guess is two in four (50%), for four inputs the likelihood is six in sixteen (37.5%), for six inputs the likelihood is twenty in sixty-four (31.25%), etc. The important point to gather from this graph is that its shape and the magnitude of the results are generally similar to those reported in the literature cited above.

4.3.2 Importance of task assignment

During the course of the experiments, it was observed that, for an organisation consisting of a fixed number of agents and tasks, just changing the connections between the tasks and the agents could significantly alter the efficiency. For example, Figure 3 (structure A) and Figure 4 (structure B) illustrate two organisational structures that are structurally similar, the only difference being the connections between the analysts and the tasks.

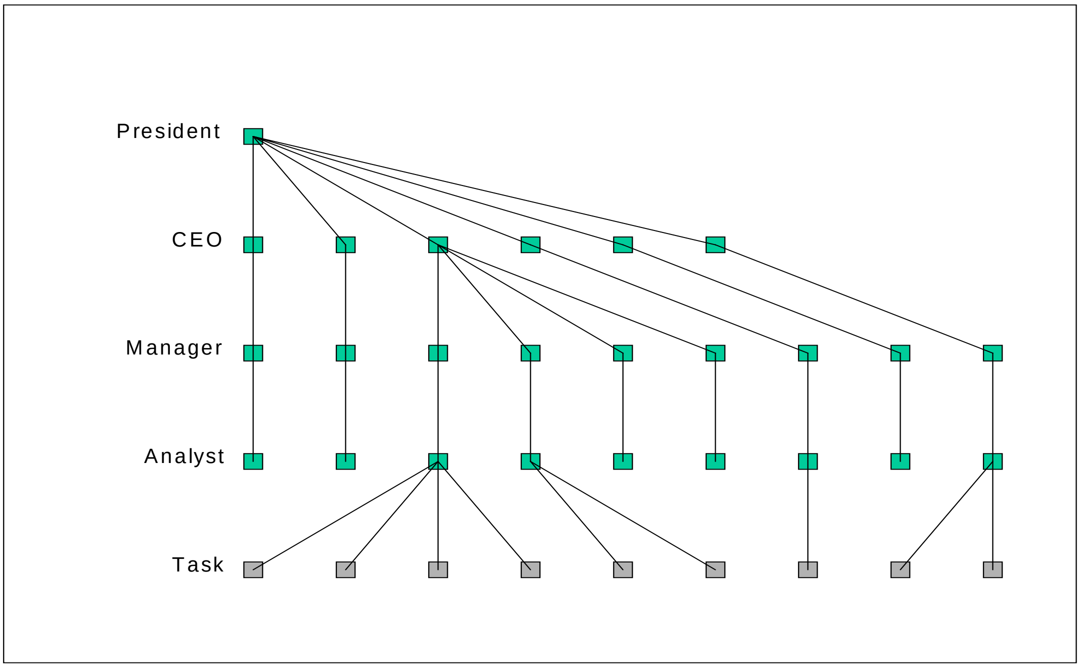

Figure 3 Task assignment A– Efficiency 60.4%

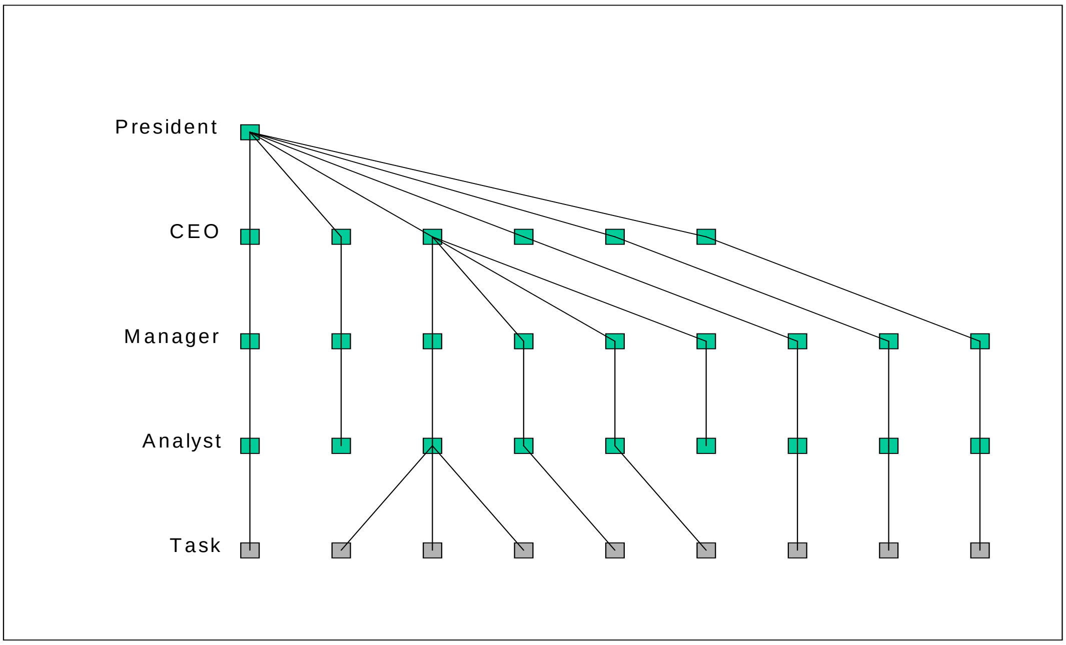

Figure 4 Task assignment B – Efficiency 88.0%

The average efficiency for task assignment A was 60.4% and the average efficiency for task assignment B was 88%, a difference of 21.6%. This result demonstrates that efficiency is sensitive to changes to the way that tasks are assigned, that is, who does what task. This result has an important implication for the practical value of using ORGAHEAD to examine specific organisational structures or modifying them to improve efficiency. The problem is one of measurement. Because organisational structures are complex there usually are practical difficulties associated in trying to identify and measure the associations between agents and tasks, hence there are likely to be uncertainties about the calculated organisational efficiencies.

4.4 Military command structures (phase 3)

4.4.1 The purpose of using military command structures

There are many types of organisational structures that are suitable for analysis. Also, there are plenty of examples (Carley 1995; Carley and Svoboda 1996; Carley 1997) that illustrate how ORGAHEAD has been used to help researchers to reason about organisations in general and to assist the building of organisational theories. The aim of this study is to determine the utility of using ORGAHEAD to explore representative military structures. The purpose in using models of military structures is to scope the type of organisations that are characterised and make the studies more meaningful to Defence clients.

4.4.2 Modelling command structures

In ORGAHEAD, individuals can represent decision-making elements. But, more generally, groups, sections, battalions, divisions, platforms, etc., can also be represented as decision-making elements. This more general concept is used in modelling the command structures used for these experiments. The models of operational command structures discussed in this report were extracted from historical examples of command arrangements used for combined, coalition, and joint operations. Only the highest strategic and operational echelons of the structures, and links to the external military environments, were considered. These structures are illustrated in Appendix C.

4.4.3 Measures for comparing models of command structures

Developing measures that are suitable for comparing the efficiencies of models of different operational command structures is difficult. How do you compare a model of the command structure of 'Operation Overlord' with that of a model of the command structure of 'Operation Desert Storm?' Command structures are never exactly the same. Each structure is populated with different numbers and types of resources; all allocated to different types of tasks. Also, the success of a military operation may rely heavily on those environmental factors that are outside of the immediate control of the operational commanders, such as the length of the logistics supply chain, the weather, the number of troops, or the amount and type of military hardware available. Successes associated with particular conflicts do not necessarily mean the existence of highly efficient and effective operational command structures. Command structures are open systems and external factors such as the type of conflict, the political objectives, and the state of readiness of the external force, all influence the amount and type of information that flows in and out of them. But the fit between external environment and structure is critical in determining the effectiveness and efficiency of an organisation (Nadler and Tushman 1997), and the variety of these factors makes it difficult for the analyst to compare organisations and make judgements on the merits of one structure against another.

4.4.4 Structures

The following eight models of operational command structures are the subject of the investigation described in this section:

- OVERLORD - allied command arrangements – Normandy, 1944;
- AOP - allied operations in the South West Pacific area, 1944-45;
- GCINCW - German command arrangements – Normandy, 1944;
- T317 - Task Force 317, British operations in the South Atlantic, 1982;
- ODS - operation Desert Storm, 1991;
- SEAC - South East Asia command, 1945;
- OSET - operation Stabilise – East Timor, 1999 – 2000; and
- PAEF - possible Australian expeditionary force, beyond 2002.

Seven of these models represent the formal operational structures that were used to perform actual military operations. The command structure models and associated text descriptions are derived from historical references. As can be seen from the diagrams (Appendix C), only the formal reporting structures of the highest levels of command are represented. Although information about the different types of informal relationships that existed may be available, during this study insufficient material was collected to build informal structures.

4.4.5 Validity of models of historical command structures

Whenever modelling is used it is often necessary to consider how well the model represents the reality it is trying to describe? Operational command structures are complex and of necessity include many elements. Consequently, there is no simple way of determining how well a proposed model represents an actual command structure. Two questions need to be answered. Firstly, how well does the model represent the known facts that were used to build the model, and were there omissions in collecting the data or mistakes made in constructing the model? Secondly, even if we have all that is necessary to build the model, how can we be sure that we have built the correct model, that is, a model that is sufficient to describe and help explain the observed reality; does the model help to answer the questions of interest?

Modelling command structures necessitates making choices about what elements to include in the model. Selection is usually based on knowing which, of all the elements, are more important. That is, what elements should be included in the model and what ones should be left out? The choices are not always easy to make and there are several factors to consider.

The models of the command structures used in these experiments are based on historical accounts, extending back more than 50 years, and the recorded view of military matters, based on knowledge of the world then, was influenced by the attitudes and values of the time. The view of organisational structures and what was important is most likely to have been strongly influenced at the time by what were then the organisational practices and cultures. If the military outcomes had been different would we have the same set of representations and relationships? Would a command structure that was partially or fully responsible for failure contain the same elements as one that was responsible for success? Even the word 'success' is not well defined. Some of today's criteria for military success (e.g., the number of acceptable casualties, or the duration of a conflict) are different to what they were 50 or more years ago: today, heavy losses means tens of casualties, but it used to mean thousands; today, the duration of a war is measured in weeks, but it used to be measured in years.

Because direct access to the past is impossible it is difficult to accurately reproduce the actual circumstances surrounding the military operations. The results from the experiments recognise these difficulties. Notwithstanding this, using representations of actual command structures does help to give useful insights about the number of elements, the shape of the structure, and the number of reporting links. The application to military structures offers insights into a method that can be used for the future modelling of ADF command structures. The organisational models help researchers to understand organisational science. Situating the experiments in actual operations helps to convey the military relevance.

4.4.6 Difficulties comparing models of command structures

The structures shown in Appendix C represent models of the formal military command structures that were used during actual operations. The operations were complex and many of the structural details are missing. The structures, as would be expected for military organisations, are generally hierarchal, but the actual spans of control at the different levels, particularly the lower levels, are difficult to estimate from the reference material (See Appendix C). The operations are different in size, objectives, place, and time; so there are difficulties in trying to make comparisons between them. If we wanted to compare the structures directly we would need to give each organisation exactly the same task and measure the outputs of the simulations. Unfortunately, the organisations were all different and they all carried out different tasks, so it is difficult to compare performance. Probably the best we can do is to capture a representation of each structure, modify it, and then compare the modified version with the original representation.

4.4.7 Experiments

The following three experiments were carried out using the military command structures:

- Experiment 1 - agents acting as majority classifiers;
- Experiment 2 - agents with experiential learning;
- Experiment 3 – adding connections with structural learning.

Each experiment was conducted in four stages: aim, method, results, and discussion.

4.5 Experiment 1 – agents acting as majority classifiers

4.5.1 Aim

The aim of this experiment was to show the relationship between efficiency and the type of command structure. Different structures should exhibit different efficiencies. To highlight the effect, changes to the structures were not allowed and all the agents were programmed to act as majority classifiers. Majority classification occurs when agents base their decisions on task input pattern majorities of either ones or zeros. To avoid interference between individual learning and structural learning, the memory of each agent was disabled so that individual (and hence organisational) learning was inhibited.

4.5.2 Method

Starting with the command arrangements for Operation Overlord (Appendix C1) the experiment was set up so that the model of the organisational structure could not change. To achieve this, simulated annealing was disabled. Individual learning was also disabled and the agents were programmed to act as majority classifiers. A binary classification task was used. In each simulation 500 tasks were executed, and the efficiency was determined after every 100 tasks; each efficiency calculation was the average of the previous 100 tasks. In addition, each simulation was carried out 100 times to determine overall average efficiencies. The ORGAHEAD parameter list is given in Appendix D1. The experiment was then repeated using the other command structures.

4.5.3 Results

Figure 5 illustrates the efficiency over time (increasing number of tasks) for each of the command structures. Five periods, each representing the average efficiencies for each period (100 tasks), are shown. The data (average relative efficiencies and standard deviations) supporting this figure are tabled in Appendix D1.

Figure 5 Efficiencies with agents acting as majority classifiers

4.5.4 Discussion

An examination of Figure 5 shows that the different organisational structures return different efficiencies. The most efficient organisational structure is GCINCW with approximately 83 percent and the least efficient is AOP with approximately 68 percent. The implication of this result is that structure has a direct bearing on the efficiency.

Figure 5 also shows that the measured efficiency for the model of each organisation is relatively constant. The average efficiency for the first 100 tasks (1 to 100) is the same (almost) as the average efficiency for the last 100 tasks (401 to 500). From this it can be concluded that efficiency is independent of the number of tasks. This is to be expected as the agents were programmed to act as majority classifiers. That is, the agents did not remember their previous decisions so they had no bearing on current or future decisions. The decisions were based only on current situation awareness, with no additional weighting being given to any particular inputs, and a rule that allows guessing in the event that an even number of inputs does not return a clear majority.

4.6 Experiment 2 – agents with experiential learning

4.6.1 Aim

The method for this experiment was similar to that used for experiment 1, but the aim here was to show that over time (a number of tasks) the agents in a command structure can learn and efficiency improves. Also of interest was the rate at which learning occurred and how long it took for the efficiency to stabilise. As the agents learned it was expected that their decision-making ability, and the overall decision-making ability of the associated command structure, would improve.

4.6.2 Method

Again starting with the command arrangements for Operation Overlord (See Appendix C1) the experiment was set up so that the model of the organisational structure could not change during the simulation. To achieve this simulated annealing was disabled. Agent learning was enabled so that each agent behaved as an experiential learner, and agents were programmed so that they did not act as majority classifiers. Agent memory was reset at the start of each simulation. The same type of binary classification task was used as for the previous experiment. 500 tasks were performed and the efficiency was calculated every 100 tasks. Again there were 100 simulations and average efficiencies and standard deviations were determined. The parameter list for this experiment is given in Appendix D2. The process was repeated for the other command structures.

4.6.3 Results

With the experiential learning enabled, Figure 6 illustrates the efficiency over time (as the number of tasks increase) for each command structure. Five periods, each representing the average efficiencies for 100 tasks, are shown. The supporting data (average relative efficiencies and standard deviations) are tabled in Appendix D2.

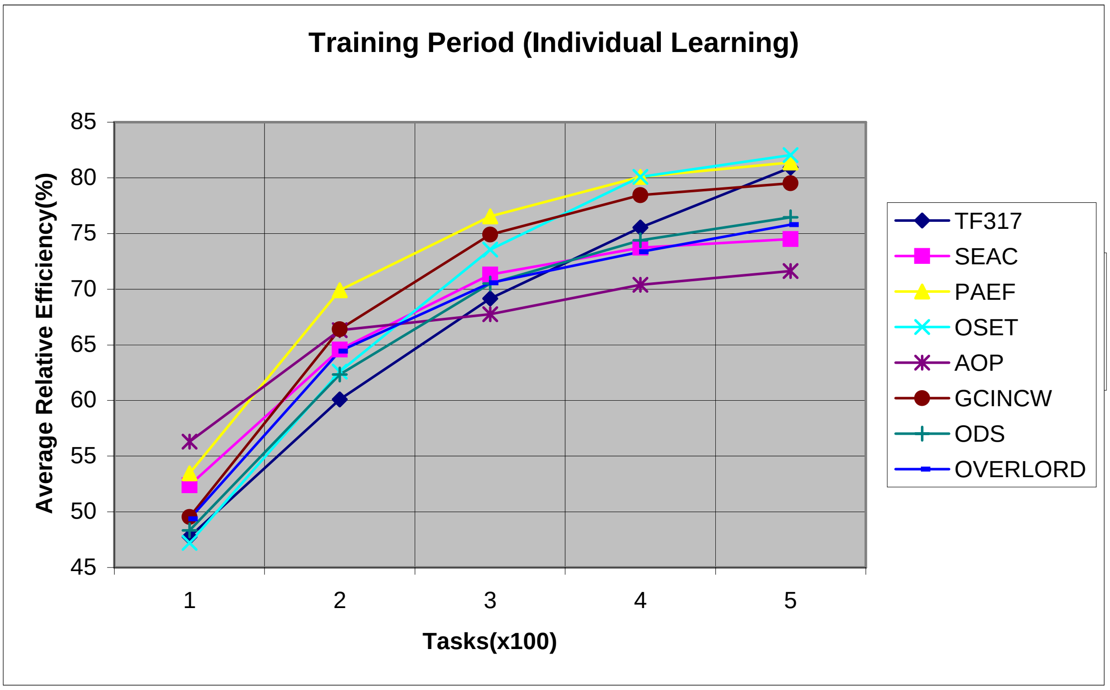

Figure 6 Agent efficiencies using experiential learning

4.6.4 Discussion

The results show that the efficiency for each organisational structure was different. In this case the efficiency of each organisation increased (generally monotonically) with the number of tasks, that is, as the individual agents gained experience. At the start of the simulation the agents started without any experience and so, without any other behavioural rules (such as behaving as a majority classifier) to guide their decisions, they guessed. The performance at the start is seen to be around 50%. As the number of tasks increased, feedback, based on the correctness or otherwise of previous choices (or guesses), guided the agents in making future decisions. The agents learned to recognise and remember patterns and used what they could recall to help them to improve their efficiencies. Generally, for each organisational structure the rate of improvement in efficiency was faster at the start of the simulation, but slowed later. It was also noted that not all of the organisational structures improved their efficiencies at the same rate. This may be structure related, the implication being that some structures facilitate learning better than others. It was noted that the best performer at the start of the simulation was AOP with an efficiency of 53.6%, while OSET was the worst with 47.2%. The best performer at the end of the simulation was OSET with 82.0%, while the worst was AOP with 71.6%. This particular example shows that what started out to be the best performer, ended up, after 500 tasks, being the worst. Figure 6 shows the crossover of the efficiency tracks for the AOP and OSET configurations. The reason for this effect needs to be explored further.

Comparison of the results of experiment 1 with those of experiment 2 shows that at the start of the simulation the organisation efficiency using agents configured to act as majority classifiers was better than organisation efficiency using agents as experiential learners. The experiential learners initially guessed until they built up sufficient experience. By the end of the simulations the efficiencies were comparable, the majority classifier configurations being just slightly better, on average, than the experiential learning configurations. Increasing the number of tasks beyond 500 is likely to marginally improve the efficiencies of the experiential learner agents. The closeness of these final efficiency results supports the contention by Carley (Carley 1997) that at the limit of experiential learning, agents behave like majority classifiers.

4.7 Experiment 3 – adding connections with structural learning

4.7.1 Aim

The aim of experiment 3 was to determine the efficiency when the number of connections was increased. Of particular interest was the relationship between the overall efficiency of the models of the organisations and the number of agent-agent connections and agent-task connections. Also of interest was the number and types of connections needed to produce maximum efficiency.

4.7.2 Method

Using the command arrangements for Operation Overlord, simulated annealing was enabled so that connections could be added. To avoid interference between the effects of experiential learning and structural learning, the experiential learning was disabled so the agents could act as majority classifiers. The number and type of agents in the structure remained the same for the duration of the experiment. The initial structural configuration is shown in Appendix C1.

20,000 tasks were carried out during each simulation. As the simulation progressed a new connection was added to the structure every 500 tasks, resulting in 40 additional connections to the original configuration. Each new connection was randomly chosen, but was either, between agents, or between agents and tasks. Again, as in the previous experiments, binary classification tasks were used. The efficiencies were recorded every 500 tasks and the results averaged over a total of 100 simulations. The parameter list for this experiment is given in Appendix D3. The method was repeated for the other command structures.

4.7.3 Results

Figure 7 shows the efficiency of each command structure model as a function of the number of connections. The horizontal axis shows the number of tasks and the number of additional connections. The data supporting this graph is in Appendix D3. The graph reflects a general trend showing that as the number of connections increased the organisational efficiency increased. The rate of change of increase in efficiency was different for each structure, but the overall increasing trend was the same. The graph does not indicate the type of connections, e.g. agent-agent or agent-task, just the number of connections.

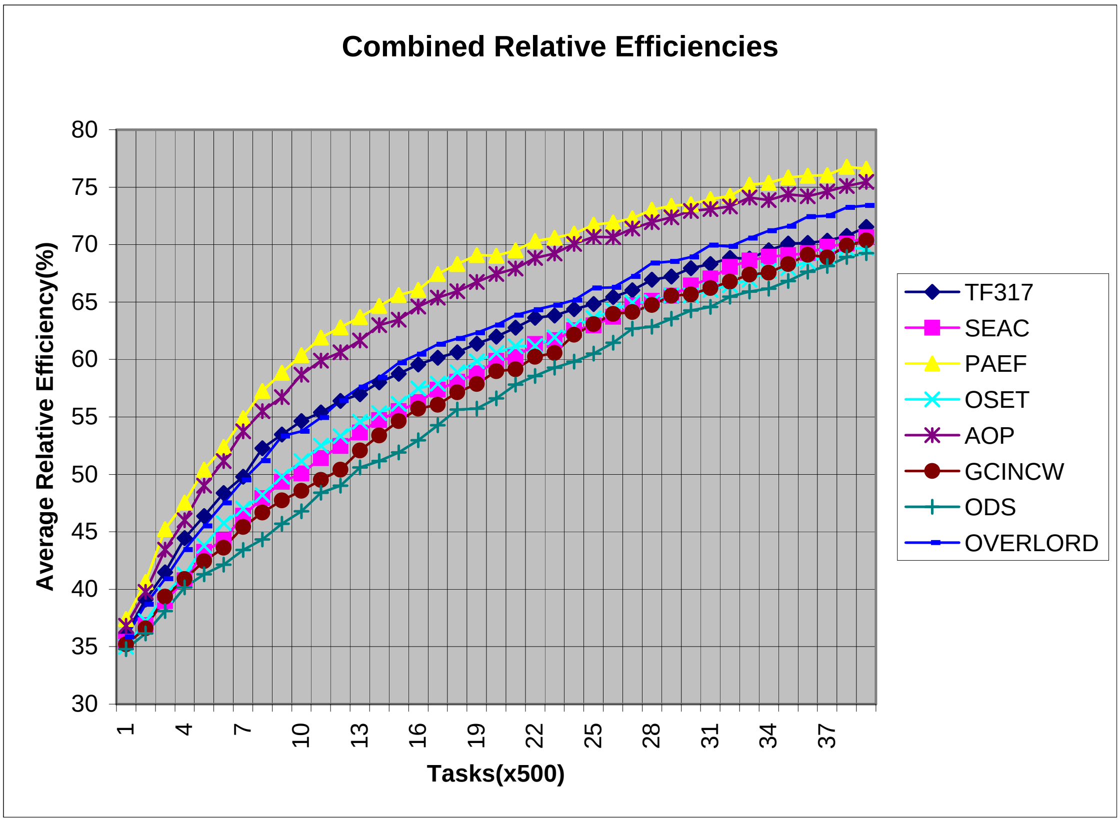

Figure 7 Efficiencies as the number of connections is increased

4.7.4 Discussion

In this experiment, structural learning was enabled and individual learning was disabled. This was done to isolate structural and individual learning. But, as can be seen from the previous experiments, structure influences efficiency. Initially, in this experiment, there were no connections between agents and tasks. The initial connections were only between the agents. So at the start the agents either acted as majority classifiers (generally supervisor agents) or they guessed because they did not have any information about the tasks. This guessing is reflected by the initial low efficiency, which was approximately 36%. As the number of randomly assigned connections was increased the efficiency started to increase, the increase being, generally, monotonic. All of the connections were between entities (agents or tasks) that were at different levels in the structure. There were no connections made between entities at the same level. This is an intrinsic design characteristic of ORGAHEAD, that is, connections between elements at the same level are not allowed.

As the number of connections increased the efficiency increased. For each simulation, the number of tasks was limited to 20,000, but in looking at the graph there is no indication that the efficiency has reached its peak. Additional experiments are needed to establish the upper limits to the number of connections that can be used. But the value of doing this from an organisational perspective also needs to be considered. Adding links allows agents at the higher levels to acquire more direct information about the tasks and decisions made at lower levels, but there are practical implications. Increasing the number of links, and hence the amount of information, can lead to information overload – especially in humans. One aim of the designers of command information systems should be to convey just the right amount of information necessary to make effective decisions. Too little information can lead to guessing, and too much information usually requires additional (and time consuming) filtering and categorising.

For ORGAHEAD structures consisting of CEOs, managers, analysts, and tasks (no president), only six different types of connections are possible. Namely, connections between the following:

- CEOs – Managers;
- CEOs – Analysts;
- CEOs – Tasks;
- Managers – Analysts;
- Managers – Tasks; and
- Analysts – Tasks.

As can be seen from Figure 7, increasing the number of connections causes an increase in the efficiency. But also of interest are the types of connections that influence efficiency. Figure 8 illustrates the changes in efficiencies for the different types of connections for the ODS organisational structure.

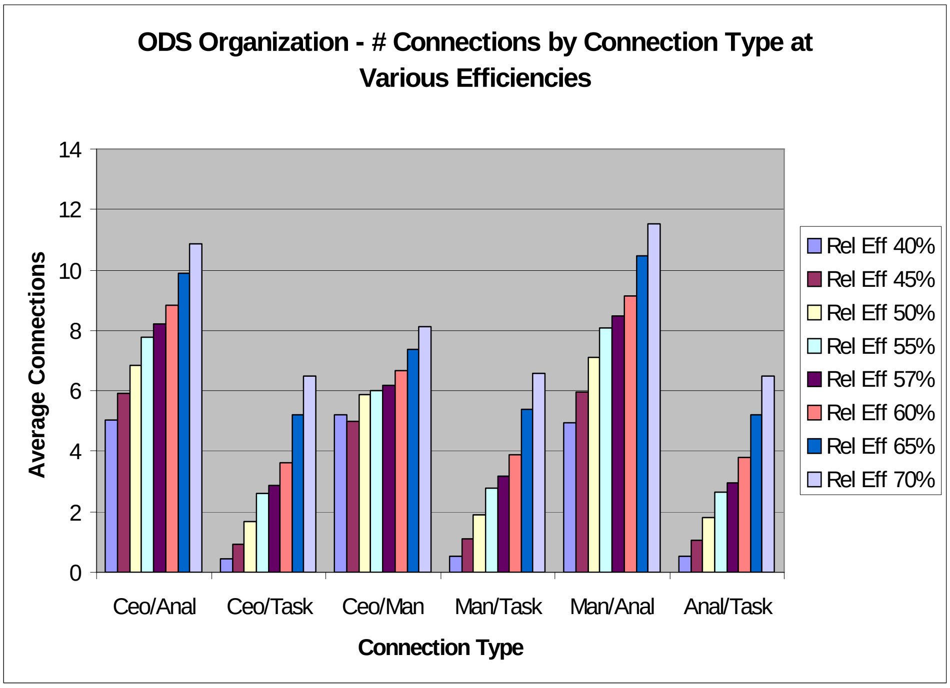

Figure 8 Efficiency vs. number and type of connection.

Increasing the number of connections gives an increase in efficiency, but what is not clear from the figure is how influential each type of connection is. Also knowing where to place additional links in order to obtain the greatest increase in efficiency is of interest. A more detailed sensitivity analysis is needed to isolate the more critical connections. But, preliminary indications are that to obtain more conclusive results more samples are needed.

This experiment looked at the effects of increasing the number of connections when individual learning was disabled. Future experiments could explore cases involving individual learning or when individual learning and structural learning are combined.

4.8 Model validation

Military command structures are complex: there are many different types of elements and relationships. Given this complexity, there is lots of work and many practical difficulties involved in trying to capture an accurate representation of the command arrangements that may have been used during an actual military operation. Referring to historical records is the only practical means available for capturing some facts, but often, this is only partially successful. Most historical accounts usually reflect the thinking that was in vogue at the time of the operation. They can be biased, narrowly focussed on particular events, and from the perspective of the researcher trying to build models of organisational structures, incomplete. Several accounts (viewpoints) are usually needed to provide a balanced account of what actually happened. Another shortcoming of historical accounts of command is that they often recount only the details of what happened at the highest levels in the command structures, usually the facts about the most historically significant characters: supreme commanders, generals, and political figures. This leaves many gaps in the historical accounts of the individuals and the working relationships that existed at the intermediate echelons in the command chains. Trying to accurately capture the details of the intermediate levels is difficult and if not done well can compromise the validity of the models.

In addition to the errors that can result from an inability to accurately capture relevant historical events, there are also other factors that can influence the ability of any modelling tool to accurately represent organisations. In organisations direct communications occurs between individuals at all levels: sideways and downwards; not only upwards. And there are other types of relationships that can exist within organisations: friendship, mentoring, authority, or accountability. Their existence also means that many other types of things go on within an organisation other than direct reporting and decision-making. Also, in organisations most of the information that influences decisions is weighted. That weighting scheme can be complex and, often, unknown: it can depend on information relevance, type, source, timeliness, and recent and/or past events. Feedback mechanisms can be complex. In some cases little feedback is needed, in others, lots. Also, limits to cognition and cognitive processes for the individual agents within an organisation can be complex, and do not always follow a rational decision-making scheme. Unless the influence of these factors is adequately accounted for within the model, the validity of the model will remain in question.

The experiments showed that efficiency can be sensitive to changes to the command structure. The implication of this finding is important. Because it is difficult to be sure about the details of the military command structure that has been captured, and because the model at best only represents an organisation from one viewpoint, namely upward reporting and decision-making, then it is unlikely that any real command structure can be accurately modelled. And this means that there will be uncertainty surrounding any results that are produced.

Conclusions

The purpose of this report was to describe the ORGAHEAD modelling method and its application to military command, and to assess the suitability of the method in supporting the organisational analysis of ADF command arrangements.

From the forgoing the following conclusions are made:

- ORGAHEAD has some utility in helping analysts to understanding aspects of organisational behaviour and to develop organisational theories.
- ORGAHEAD can be used to investigate organisation structures of intermediate size and complexity comprising agents endowed with moderate cognitive decision-making abilities.
- Due to shortcomings in what can be represented in ORGAHEAD it has limited utility in helping analysts to analyse and compare the decision-making characteristics of military command structures.
- ORGAHEAD is a research tool that throughout the period of this investigation was undergoing development: there were several software modifications made by CASOS to upgrade its capability, improve the user interface, and to overcome software bugs. Robustness issues need to be addressed before embarking on any future investigations.
- ORGAHEAD is one of a suite of organisational analysis tools being developed and supported by the CASOS, but many of the features offered by the tool are yet to be fully explored. The exploration of these features is likely to require extensive CASOS support.
- Using historical records to accurately capture the relevant detail of specific military command structures for modelling purposes is time consuming and prone to errors of omission and accuracy.
- Because of the complex nature of the command structures used for large-scale military operations, it is difficult to capture the relevant detail and validate the models of specific command structures.
- The results obtained from the experiments using ORGAHEAD apply only to the models of the military organisation structures represented, not to the actual organisation structures.
- The sensitivity of efficiency to changes in structure, along with the difficulties of capturing organisation details, limits the practical utility of ORGAHEAD for analysing and comparing specific command structures.

5. Recommendations

It is recommended that:

- To overcome difficulties with software development and the modification of ORGAHEAD, any future investigations involving ORGAHEAD are carried out in conjunction with researchers at the CASOS.

- Investigations involving ORGAHEAD should concentrate on organisational theory building and the more general nature of reporting and decision-making across a wide range of types of command structures.

- Further experiments that are carried out to identify the characteristics of ADF operational-level command structures make use of a variety of organisational modelling approaches.

6. Acknowledgements

The authors are grateful to members of the Centre for Computational Analysis of Social and Organisational Systems (CASOS) at the CMU. In particular, thanks to Professor Kathleen Carley who provided the ORGAHEAD and the support documentation, and to Ju-Sung Lee who provided software upgrades, bug fixes, and general operational advice.

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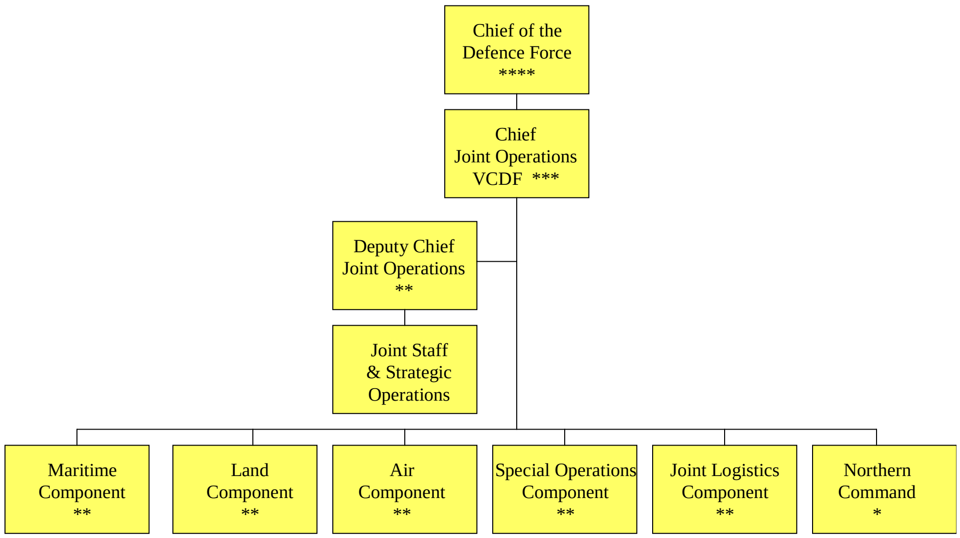
Appendix A: ADF Command Arrangements



Refer to Defgram No 136/2004

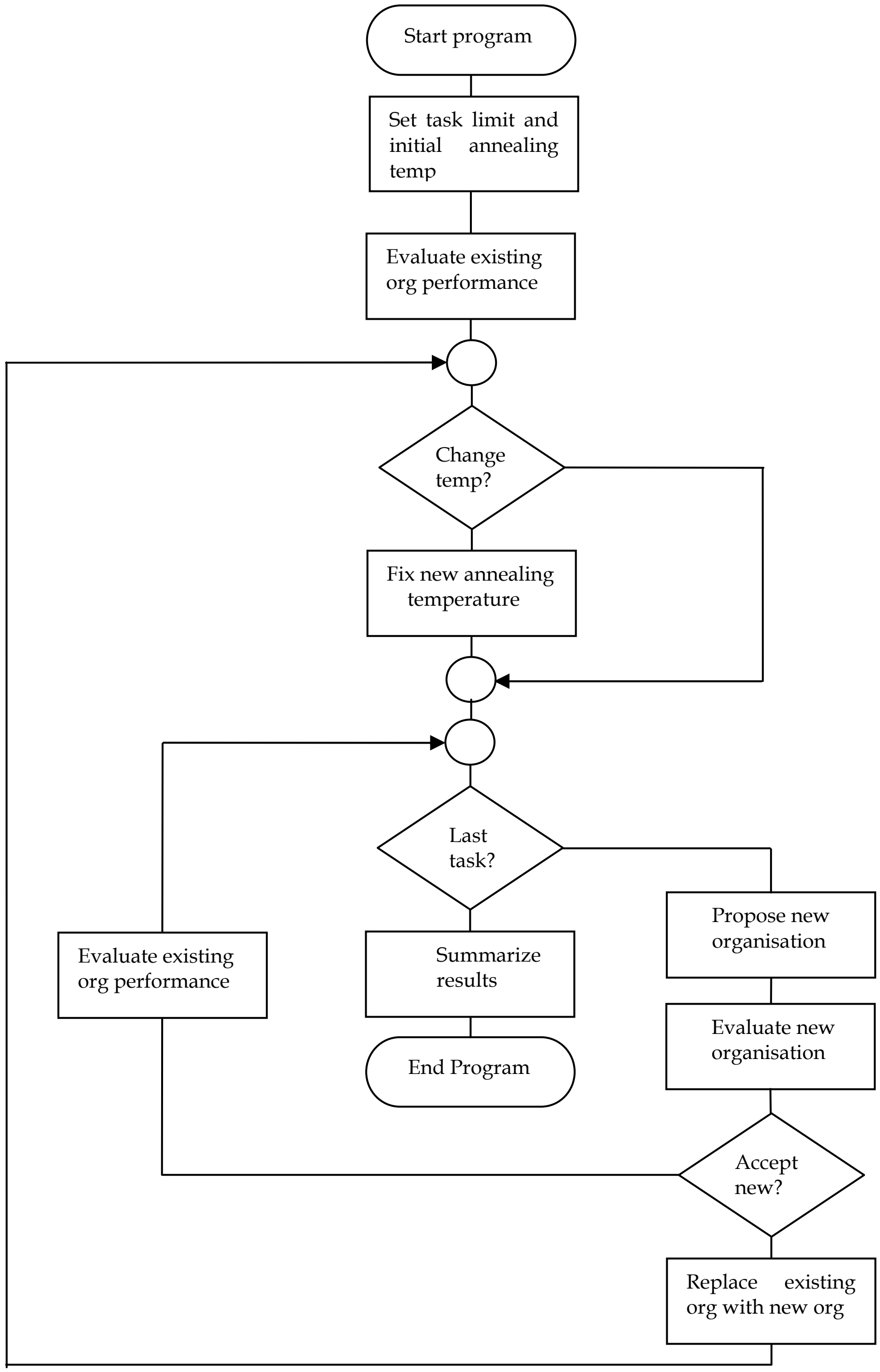
Appendix B: Simulated Annealing

B.1. ORGAHEAD flow chart details

The first step carried out by the ORGAHEAD program (refer to ORGAHEAD flow chart in Appendix B2) is to load default and user defined parameters. These include: the number of simulations, the type of organisational structure, the maximum number of tasks, the annealing characteristics, and the types of changes that are allowed for the each simulation. After a period of training the efficiency is determined. During training the agents (and effectively the organisation) have the opportunity to recognise particular input patterns and over time remember and improve the way they respond to particular inputs, and in so doing improve the overall efficiency of the organisation.

Once the efficiency of the existing organisation has been determined a new organisation is proposed. After a period of training, the efficiency of the new organisation is determined and compared to the efficiency of the existing organisation. If the efficiency of the new organisation is better than that for the existing organisation then the existing organisation is replaced by the new organisation, otherwise, and depending on the Metropolis criterion (see Appendix B4), the existing organisation will remain. The Metropolis criterion is part of the simulated annealing algorithm and is used to allow one of the proposed organisations, from ones which do not perform as well as the existing organisation, to replace it. This acceptance of an organisation that does not perform as well as the existing organisation, a feature of the simulated annealing algorithm, effectively works towards preventing the organisational search process from stopping at the first local maximum. The algorithm does have the disadvantage of accepting a few organisations that don't perform as well as existing organisations, but, even though it does not always guarantee the highest efficiency, the extensive searching feature does avoid local maxima.

B.2. ORGAHEAD Flow Chart



B.3. Description

Simulated annealing (Kirkpatrick, Gelatt et al. 1983) (Rutenbar 1989) is an optimisation technique that has been identified as being analogous to the slow cooling (annealing) process that can be applied to a physical solid. When a solid is heated the energy of the molecules increase and their random motion becomes more intense. If the temperature is dropped suddenly the molecules may 'freeze' and settle in a disordered and stressed state, leaving the solid brittle and more likely to fracture. Annealing is a technique that can be used to relieve this molecular stress and return the solid to a more malleable low energy state. To anneal a solid after heating, it is necessary to allow it to cool slowly (usually by controlling the rate at which heat is allowed to flow away) so that the molecules have a greater time in which to settle into a regular (less stressed) orientation.

Simulated annealing is used to find the optimum value of a multivariate discrete or continuous function. The optimum value corresponds to the minimum energy state for the system being represented. The function describes a conceptual N parameter 'landscape'. Because of the complex nature of the function there are likely to be many local minima or maxima across the landscape. The local minima are analogous to the many possible low energy states that can be taken up by a solid when the molecules in the heated solid are suddenly cooled. The simulated annealing process searches for the minimum energy state for the function (through an incremental variation of the parameters), and tries to avoid the trap of settling for the first local minimum that is identified. To achieve this, all of the steps that move the function towards a lower energy state are accepted, but, in addition, some (depending on a pre-assigned probability) of the steps that may move it towards a higher energy state are also accepted. The concept of temperature is retained and is used to control the probability schedule. Initially, the temperature is set at a high value and there is a high probability that the energy state of the function will be allowed to increase. This allows the algorithm more freedom to explore a greater area of the landscape. As the search progresses the temperature is slowly decreased, which decreases the probability that the energy state of the function will be allowed to increase. Over time, this produces less movement over the landscape and the final energy state settles around a minimum value. The basis for the search algorithm is the Metropolis algorithm, as reported in Rutenbar (Rutenbar 1989). The Metropolis algorithm uses the Boltzmann distribution from statistical mechanics to determine the probability of accepting a move to a higher energy state. The Boltzmann distribution finds application in the molecular science of solids and gases. The probability P that a move will be accepted is given by:

$$P = P_o \mathrm{Exp} {-\Delta E/T}$$

Where, P is in the range 0 to 1;
P_o is the initial probability;
ΔE is the change in energy level between states; and
T is the temperature.

From this equation, if T is large compared to ΔE, then $\Delta E/T$ is small and the probability of the move being accepted is high. Because the search across the landscape is not exhaustive, and because the function may not be well behaved (there may be point discontinuities), there is no guarantee that this final local minimum is the overall minimum value for the function. Although, for certain types of problems, in which judicious choices for the initial temperature and rate of change of temperature have been made, the method is more efficient than just randomly searching the landscape looking for local minima (Rutenbar 1989).

The cooling ratio is the rate of decrease of probability that the energy state of the function will increase. The optimum value chosen for cooling ratio depends on the organisational complexity and the shape of the performance (efficiency) landscape. Because some organisations are more complex than others they need different cooling ratios.

B.4. Metropolis Algorithm**

Simulated annealing Metropolis algorithm:

```
M = number of moves to attempt;
T = current temperature;
For m = 1 to M {
    Generate a random move, e.g., move a particle;
    Evaluate the change in energy, ΔE:
    If (ΔE < 0) {
        /* downhill move: accept it*/
        accept this move, and update configuration;
    }
    else {
        /* uphill move: accept maybe*/
        accept with probability P = e^(-ΔE/T) ;
        update configuration if accepted;
    }
} /* end for loop*/
```

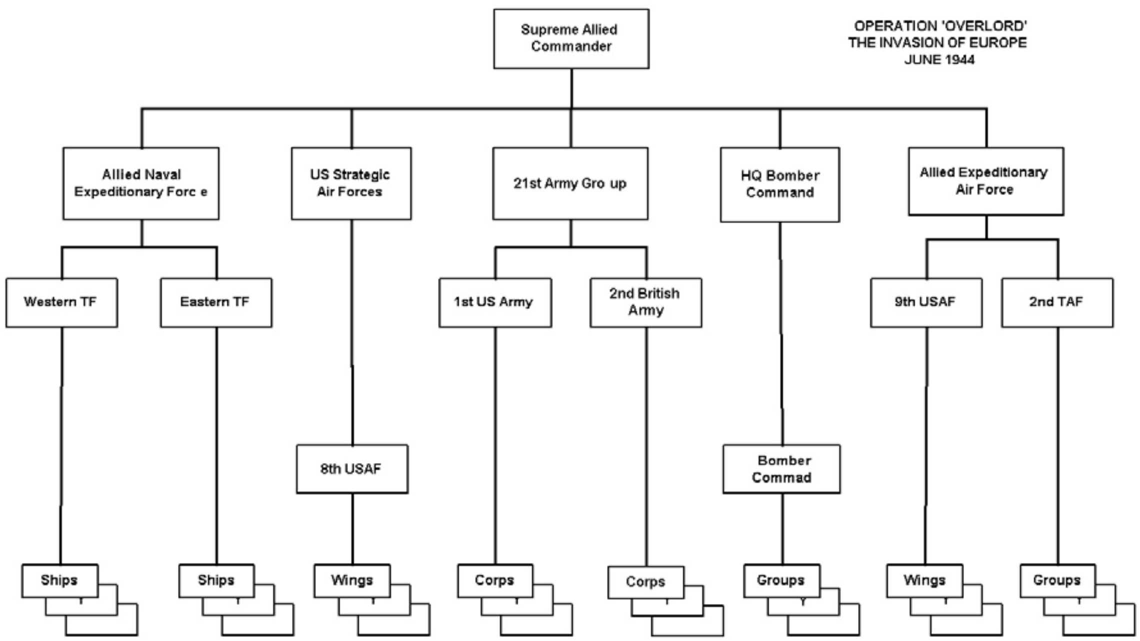
** (from Rutenbar 1989)

A more detailed description of ORGAHEAD and simulated annealing can be found at the CASOS web site: http://www.casos.cs.cmu.edu/projects/OrgAhead/

Appendix C: Historical Command Structures

C.1. Allied Command Arrangements – Normandy 1944 (OVERLORD)

Structure Chart:



Description:

This chart details the command arrangements available to the Supreme Allied Commander, General Eisenhower, for Operation Overlord, the invasion of Europe in June 1944.

References:

Ambrose, S.E., 1983, Eisenhower, Vol. 1, Simon and Schuster, New York, USA.

Eisenhower, D.D., 1948, Crusade in Europe, William Heinemann Limited, London, UK.

Bryant, A. 1957, The Turn of the Tide, Based on the War Diaries of Field Marshal Viscount Allanbrooke, Collins, London, UK.

Ferrell, R.H. (ed), 1981,The Eisenhower Diaries, W.W.Norton & Company, New York, USA.

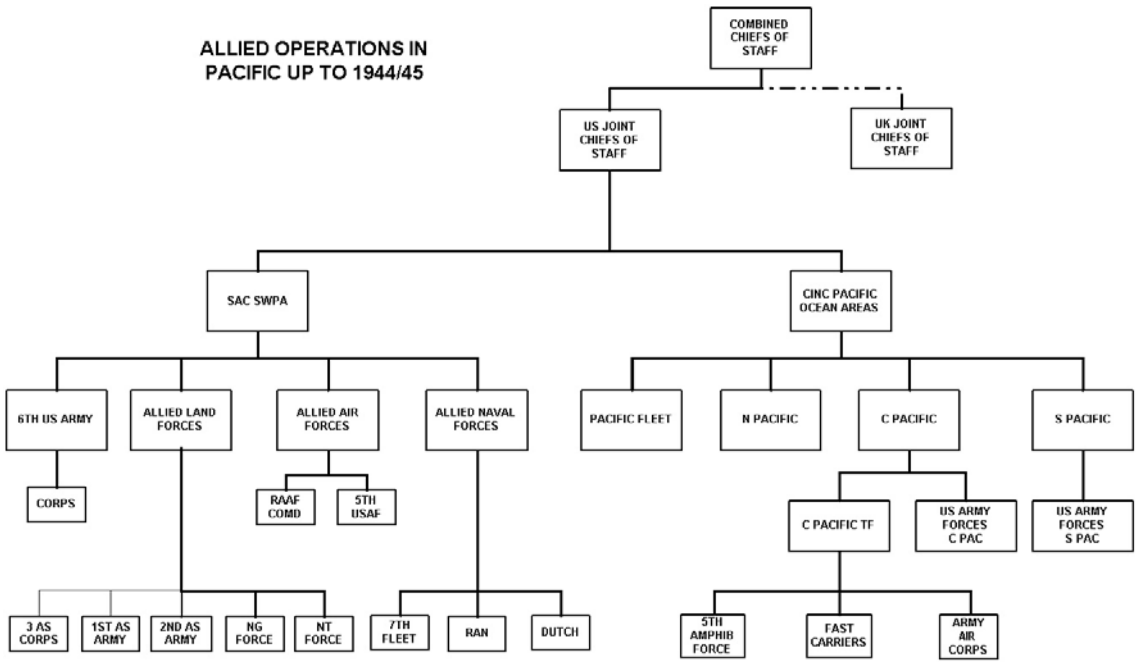
Hufford, N., 1973, Dwight David Eisenhower, US Army Center of Military History, [Online, accessed 11 Oct. 01],
URL: http://www.army.mil/cmhpg/brochures/ike/ike.htm.

Lyon, P., 1974, Eisenhower: Portrait of a Hero, Little, Brown and Company, Toronto, Canada
Montgomery, B.L. 1960, The Memoirs of Field Marshal Montgomery, Fontana Books, London, UK

Pierce, M.A., 1996, The Battle for Normandy, An Overview, Rochester University, Rochester, New York, USA. [On line, accessed 18 Oct 01], URL:www.history.rochester.edu/mtv/overview.htm.

C.2. Allied Operations South West Pacific Area, 1944-45 (AOP)

Structure Chart:



Description:

During WWII, the Pacific Ocean region was divided into two regions under two allied commanders. The South West Pacific Area (SWPA) was a theatre under Supreme Commander (General MacArthur). The remaining area, which substantially covered the remainder of the Pacific Ocean, was under Admiral Nimitz.

References:

Buchanan, D. 1987, Field Marshal Sir Thomas Blamey and the Exercise of High Command in Australia, *Defence Force Journal*, No. 62, January/February 1987, Australian Government Publishing Service, Canberra, Australia.

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Horner, D. 1982, High Command. Australia & Allied Strategy 1939-45, Australian War Memorial, Canberra, Australia.

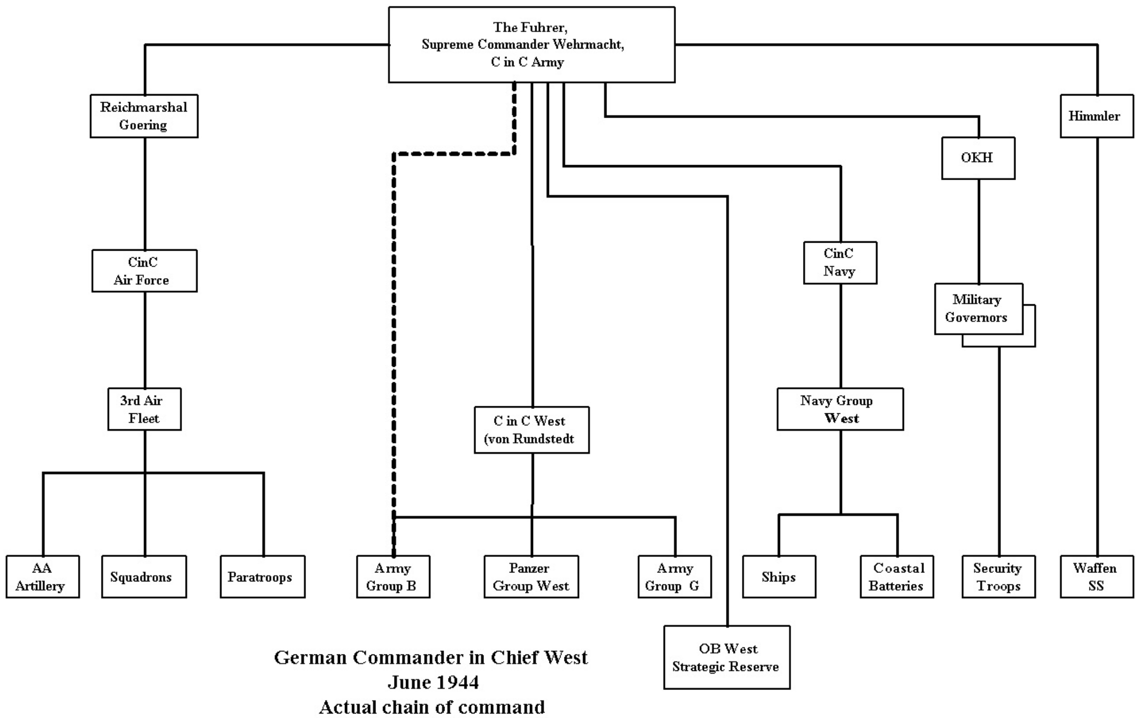
Manchester, W, 1978, American Caesar. Douglas MacArthur 1880-1964, Dell Publishing Co., New York, NY, USA.

Manuel, K.T., and Cochran, A.S., 1996, General Kenney as a Strategic Leader, Air War College, Air University, [Online accessed, 24 Oct. 01],
URL: http://www.au.af.mil/au/database/research/ay1996/awc/manuel_kl.htm

Morton, L., 1961, Pacific Command: a Study in Interservice Relations, Harmon Memorial Lecture #3, USAF Academy, [Online, accessed 13 Sep 01], URL: www.usafa.mil/dfh/HML.html.

C.3. German Command Arrangements – Normandy, 1944 (GCINCW)

Structure Chart:



Description:

This chart shows the command arrangements for Field Marshal von Rundstedt's defence of Western Europe from the threatened allied invasion. It illustrates the 'stove piped' approach taken to ensure that power was retained in Hitler's hands at the highest national strategic level.

References:

Dahl, A.B. 1996, Command Dysfunction: Minding the Cognitive War, School of Advanced Airpower Studies, Air University, Maxwell AFB, Alabama, USA, [Online: accessed 18 October 2001], URL: http://www.fas.org/man/eprint/dahl.htm

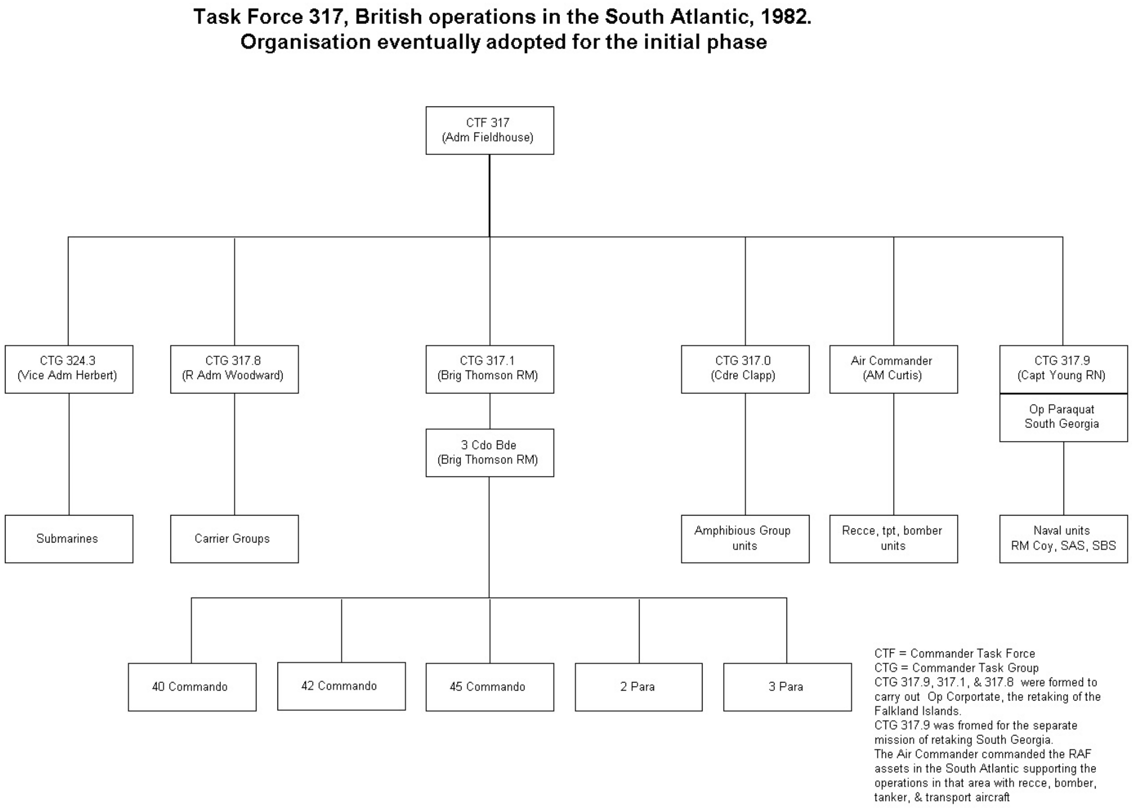
German Forces, Grolier on line, "Recovery of France", [Online: accessed 18 October 2001], URL: http://gi.grolier.com/wwii/wwii 5.html

Order of Battle of German Forces in the West, [Online: accessed 18 October 2001], URL: http://home13.inet.tele.dk/ash/orderofbattle.htm

Pipes, J., 2001, German Command and Tactics in the West, 1944,
[Online, accessed 28 Sep 01], URL:www.feldgrau.com/command44.html

C.4. Task Force 317, British operations South Atlantic, 1982 (TF317)

Structure Chart:



Description:

This chart illustrates the organisation adopted by the UK for the retaking of the Falkland Islands from the Argentineans in 1982. It is an example of a reasonably sized joint operation, involving the Navy, the Army, Marines, Special Forces, and the Air Force, conducted over long lines of communication. The commander controlled three largely independent activities: the submarines in the South Atlantic, the recapture of South Georgia Island by special forces, and the retaking Falkland Island.

References:

Battles of the Falklands Islands War 1982, [Online, accessed 25 March 2003], URL: http://www.naval-history.net/NAVAL1982FALKLANDS.htm

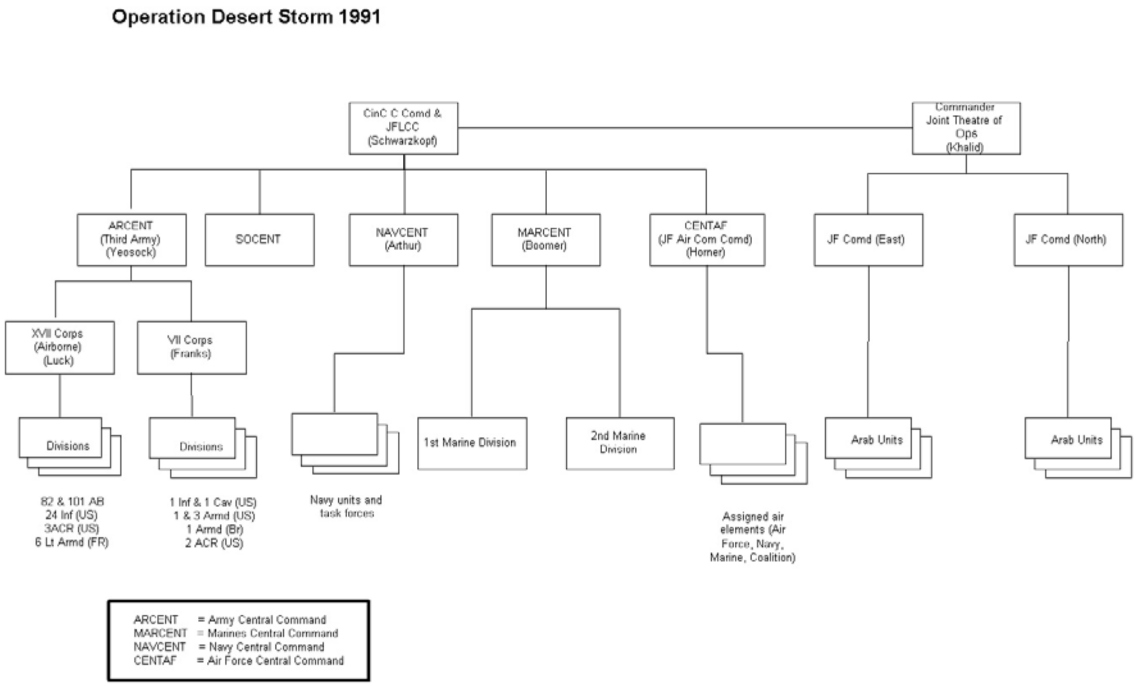
Clapp, M., and Southby-Tailyour, E., 1996, Amphibious Assault Falklands: The Battle for San Carlos Water, Naval Institute Press, Annapolis, USA.

Middlebrook, M, 2001, The Falklands War 1982, Classic Military History series, Penguin Books, London, UK
Satchwell, M. and Sproles, N. pers.com., December 2001.

Thompson, J. 1992 reprint, No Picnic, Leo Cooper, London, UK.

C.5. Operation Desert Storm, 1991 (ODS)

Structure Chart:



Description:

Operation Desert Storm was carried out in 1991 to remove the invading Iraqi forces from Kuwait. The chart shows the hybrid parallel command system where command was divided between the forces from the western coalition partners and those from Muslim nations.

References:

Cordingley, P. 1996, In the Eye of the Storm, Coronet Books, London, UK,
ISBN 0 340 68246 9

De La Billiere, P. 1993, Storm Command, Harper Collins, Glasgow, UK,
ISBN 0 00 637969 9

McCarthy, D.J., and Medlin, S.A. 2000, Two Hats for the Joint Force Commander?, *Joint Forces Quarterly,* No. 25, Summer 2000, pp. 91 – 98, Institute for National Strategic Studies, National Defense University, Washington DC, USA

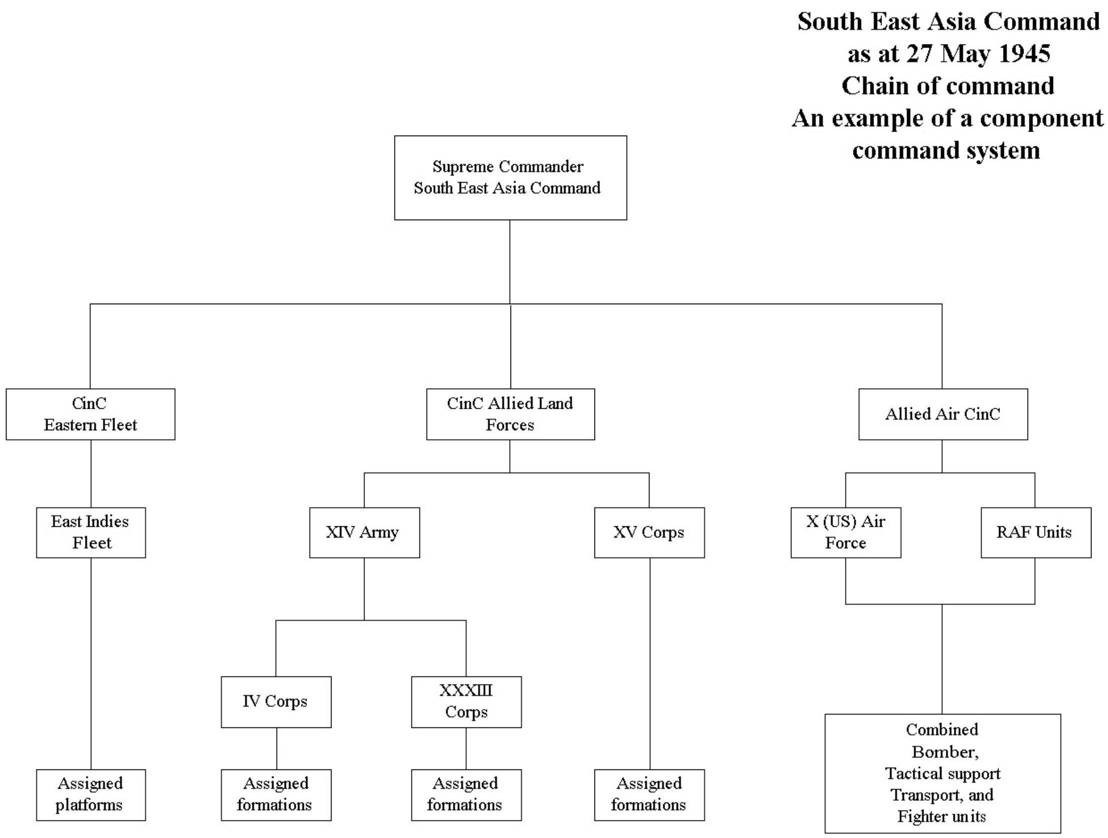
Schwarzkopf, S.N, 1992, It Doesn't Take a Hero, Bantam Books, New York, USA.
ISBN 0-553-08944-7

Swain, R.M., 1994, 'Lucky War. Third Army in Desert Storm, U.S.Army Command and General Staff College, Fort Leavenworth Press, Kansas, USA.

Wheatley, G., and Buck, D., 1999 Multi-National Command and Control-Beyond NATO , 1999 Command and Control Research and Technology Symposium, United States Naval War College, Newport, RI, June 29-July 1, 1999, [Online, accessed 25 March 2003], URL: http://www.dodccrp.org/

C.6. South East Asia Command 1945 (SEAC)

Structure Chart:



Description:

This theatre was based in Burma and was established for the liberation of large areas of South and South East Asia from the Japanese during WWII. It was commanded and directed by the British although containing large numbers of US forces.

References:

Bryant, A. 1957, The Turn of the Tide, Based on the War Diaries of Field Marshal Viscount Allanbrooke, Collins, London, UK.

Collier, B. 1969, The War In The Far East, 1941 – 1945. A Military History, Heinemann, London, UK

Hart, B.H.L., 1970, History Of The Second World War, Cassell, London, UK.

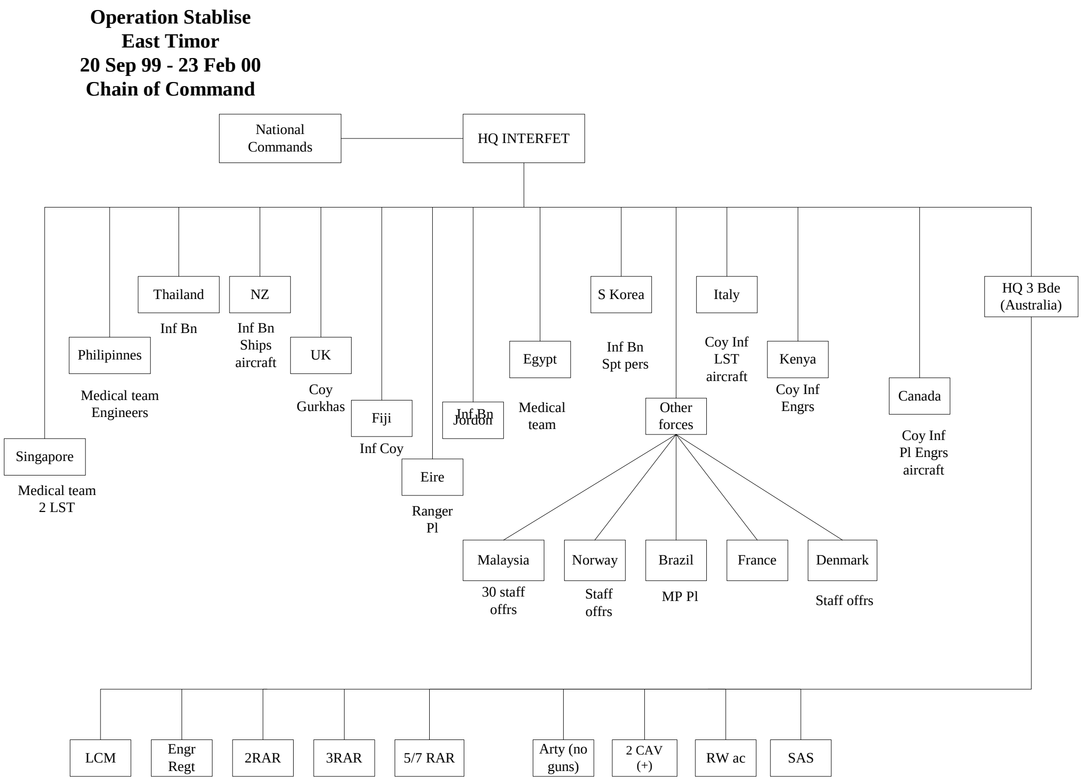
Howard, M., 1972, Grand Strategy, Volume IV, August 1942 – September 1943, HMSO, London, UK.

McGeoch, I. 1996, The Princely Sailor. Mountbatten of Burma, Brassey's, London, UK, ISBN 1 85753 161 2Hardcover.

Ziegler, P., 1986, Mountbatten, Fontana/Collins, Glasgow, UK.

C.7. Operation Stabilise – East Timor, 1999 – 2000 (OSET)

Structure Chart:



Description:

This chart shows the organisation used for the International Force East Timor (INTERFET) during the period 20 September 1999 to 23 February 2000. It shows the various national forces reporting directly to the commander INTERFET with a breakdown of the more substantial Australian forces present as part of Operation Warden. A feature of this chart is the broad span of control required.

References:

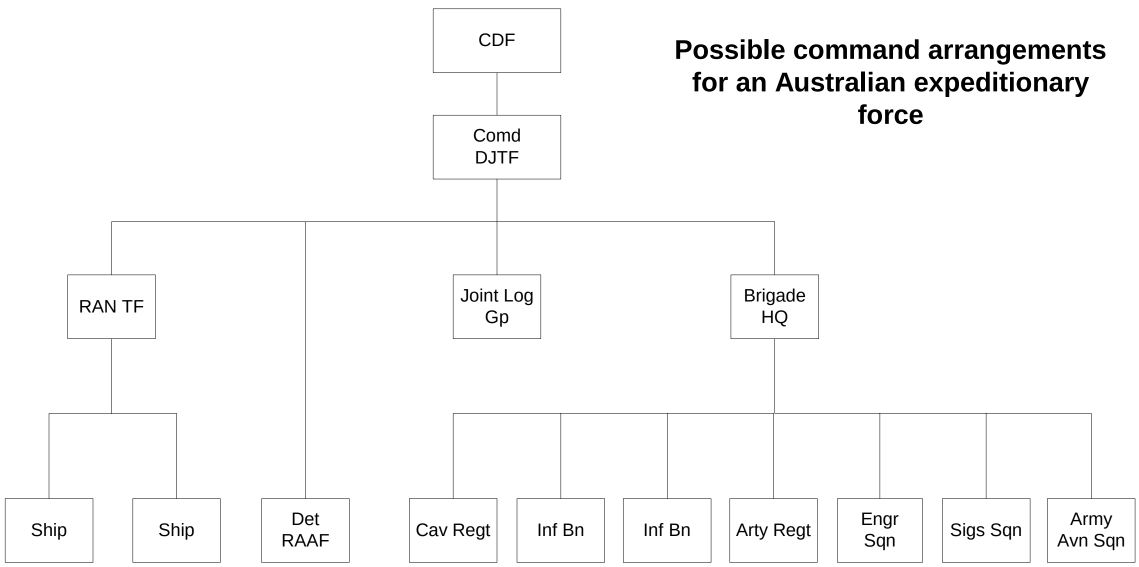
Ayling, S., and Guise, S. 2001, UNTAC and INTERFET – A Comparative Analysis, *Australian Defence Force Journal*, No.150, September/October 2001, National Capital Printing, Canberra, Australia

Ryan, A. 2000, 'Primary Responsibilities and Primary Risks, Australian Defence Force Participation in the International Force East Timor, Land Warfare Studies Centre, Duntroon, ACT, Australia.

Ryan, A. and Sproles, N. *pers.com.*, 2002

C.8. Possible[19] Australian expeditionary force, beyond 2002 (PAEF)

Structure Chart:



Description:

This is an imaginary[20] force structure for an Australian force using a Deployable Joint Task Force commander reporting directly to the CDF. This is an instance where the CDF makes the commander of a DJTF deployed overseas an operational commander.

---

[19] This structure is based on command arrangements that existed prior to the introduction of the new command and control arrangements for the ADF that established the position of Chief of Joint Operations (CJOPS). (See DEFGRAM NO 136/2004.)

[20] The structure is imaginary. The basis for its creation is the result of reading historical accounts of actual military operations and command arrangements, and general discussions with ADF personnel and DSTO researchers.

Appendix D: Experiment data

These parameters were used with the experiments. The parameter list includes the AOP structure as an example. All other parameters not specifically mentioned were left at their default values. The software version of ORGAHEAD used was Version 2.1.3. Refer to the CASOS website for further details, and tutorials, on how to set up the parameters and run an experiment using ORGAHEAD.

D.1. Experiment 1 – agents acting as majority classifiers

In this experiment the agents acted as majority classifiers. The command line used to set the parameters for this experiment was:

d:/org213/orgahead.exe -tl 1000 -pcf 85 -pch 85 -tf .5 -tn .0 -th .5 -ip .9 -fp .1 -mc 500 -ec 100 -s -p -c AB 0I -m ABCD EFGH -a A B C D E F G H -pc -po -pe

Table D-1 contains the data used to construct Figure 5. It shows the command structure efficiency (with standard deviations) over time (increasing number of tasks) for each command structure. Five periods, each representing the average efficiencies for 100 tasks, are tabled.

Table D-1 Efficiencies of command structures using agents acting as majority classifiers

	100	**200**	**300**	**400**	**500**
OVERLORD	79.0 (3.9)	78.3 (4.3)	78.3 (3.7)	77.9 (3.7)	78.5 (3.9)
TF317	82.8 (3.4)	82.5 (3.8)	82.2 (4.0)	81.9 (3.3)	82.1 (3.7)
SEAC	73.7 (4.3)	74.3 (4.6)	74.0 (5.0)	74.3 (4.3)	73.5 (4.1)
PAEF	78.3 (4.4)	78.5 (4.2)	78.2 (4.1)	78.4 (4.3)	78.1 (3.7)
OSET	82.9 (3.3)	82.0 (3.8)	83.2 (3.7)	82.9 (4.3)	82.1 (3.4)
AOP	68.6 (4.6)	67.5 (5.2)	67.5 (5.0)	67.4 (4.7)	67.3 (4.1)
GCINCW	83.3 (3.5)	83.2 (3.9)	83.6 (3.7)	82.9 (4.1)	82.9 (4.0)
ODS	78.5 (4.0)	78.2 (4.3)	78.4 (4.0)	78.5 (3.9)	78.7 (3.4)

D.2. Experiment 2 – agents with experiential learning

In this experiment the agents acted as experiential learners. The command line used to set the parameters for this experiment was:

d:/org213/orgahead.exe -tl 1000 -pcf 85 -pch 85 -tf .5 -tn .0 -th .5 -ip .9 -fp .1 -mc 500 -ec 100 -p -c AB 0I -m ABCD EFGH -a A B C D E F G H -pc -po -pe

Table D-2 shows the data use to construct Figure 6. It shows the efficiencies (with standard deviations) for the command structures with agent experiential learning enabled. Five periods, each representing the average efficiency for 100 tasks, are tabled.

Table D-2 Efficiencies using agents with experiential learning

	100	**200**	**300**	**400**	**500**
OVERLORD	49.4 (6.1)	64.4 (6.0)	70.6 (5.4)	75.8 (5.6)	75.8 (4.7)
TF317	47.8 (6.3)	60.1 (5.8)	69.2 (6.7)	75.6 (6.0)	80.9 (4.1)
SEAC	52.4 (6.2)	64.6 (6.1)	71.3 (5.9)	73.7 (5.1)	74.5 (4.5)
PAEF	53.5 (5.2)	69.9 (6.4)	76.6 (4.6)	80.1 (4.1)	81.4 (4.4)
OSET	47.2 (5.7)	62.6 (6.1)	73.6 (6.1)	80.1 (4.5)	82.0 (3.9)
AOP	56.3 (5.6)	66.3 (4.3)	67.8 (5.2)	70.4 (5.7)	71.6 (5.1)
GCINCW	49.5 (5.1)	66.4 (5.5)	74.9 (5.5)	78.5 (4.3)	79.5 (4.4)
ODS	48.4 (5.8)	62.4 (6.3)	70.5 (6.0)	74.4 (5.3)	76.5 (4.2)

D.3. Experiment 3 – adding connections

In this experiment the number of connections between the agents and between the agents and tasks was increased. Initially, there were no connections between agents and tasks. The command line used to set the parameters for this experiment was:

d:/org213/orgahead.exe -tl 20000 -pcf 85 -pch 85 -tf .5 -tn .0 -th .5 -ip .9 -fp .1 -mc 500 -ec 500 -eapp -eapt -s -p -c AB - -m ABCD EFGH -a - - - - - - - - -pc -po -pe

Table D-3 shows the data used to construct graph shown in Figure 7. It shows the efficiency (each calculated using 100 simulations) as the number of tasks is increased (to a maximum of 20,000) using the different command structures. Every 500 tasks the number of connections between structural elements is increased by one.

Table D-3 Efficiencies with increasing number of connections

TF317	SEAC	PAEF	OSET	AOP	GCINCW	ODS	OVERLORD
36.1	35.4	37.4	35	36.8	35.2	34.8	35.8
39.1	36.9	40.6	37.2	39.8	36.6	36.1	38.7
41.5	39	45.2	39.5	43.4	39.4	38.1	40.9
44.4	40.8	47.5	41.3	46	40.9	40.2	43.4
46.4	43.3	50.4	43.8	49	42.4	41.3	45.5
48.4	44.3	52.4	45.8	51.2	43.6	42.1	47.5
49.8	46.4	54.9	47	53.7	45.4	43.4	49.5
52.3	47.9	57.3	48.2	55.5	46.7	44.3	51.2
53.5	49.4	58.8	49.8	56.7	47.7	45.7	53.3
54.6	50.1	60.4	51.2	58.7	48.6	46.8	53.8
55.4	51.4	61.9	52.5	59.9	49.5	48.4	55
56.4	52.5	62.8	53.3	60.6	50.4	49	56.4
57	53.6	63.7	54.6	61.7	52.1	50.6	57.6
58	54.7	64.7	55.3	63	53.4	51.2	58.4
58.8	55.5	65.6	56.1	63.5	54.6	51.9	59.7
59.6	56.3	66.1	57.5	64.6	55.7	53	60.5
60.2	57.4	67.4	57.9	65.4	56	54.3	61.3
60.6	58.1	68.3	58.9	65.9	57.1	55.6	61.8
61.4	58.8	69.1	59.8	66.7	57.9	55.7	62.3
62	59.9	69	60.6	67.4	59	56.6	63
62.8	60.2	69.5	61.1	67.9	59.1	57.8	63.8
63.6	61.3	70.3	61.2	68.8	60.2	58.6	64.3
63.8	61.7	70.6	61.9	69.2	60.6	59.3	64.7
64.4	62.6	71	62.9	70.1	62.2	59.8	65.2
64.8	63	71.7	63.6	70.7	63.1	60.5	66.2
65.4	63.7	71.9	64.3	70.6	64	61.5	66.3
66	64.7	72.3	64.9	71.4	64.1	62.7	67.2
66.9	65.1	73	65	72	64.7	62.8	68.4
67.2	65.6	73.4	65.6	72.4	65.5	63.5	68.5
67.9	66.4	73.5	65.6	72.9	65.7	64.3	68.9
68.3	67.1	73.9	66.1	73.1	66.2	64.6	69.9
68.8	68.1	74.2	66.5	73.3	66.8	65.5	69.9
68.8	68.6	75.2	66.9	74.1	67.4	65.9	70.6
69.5	68.9	75.4	67.7	73.9	67.6	66.2	71.2
70.1	69.1	75.8	68	74.4	68.3	66.8	71.6
70.1	69.3	76	68.5	74.2	69.1	67.6	72.4
70.3	69.8	76	69	74.6	68.9	68.1	72.5
70.8	70.1	76.8	69.6	75.1	69.9	68.9	73.2
71.5	70.7	76.6	69.7	75.5	70.4	69.3	73.4

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Modelling Operational Command Structures using ORGAHEAD

Alex Yates, Ashley Cook and Noel Sproles

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Director General Joint Operations	Doc Data Sheet
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Commandant ADF Warfare Centre	Doc Data Sheet
Director General Strategic Logistics	Doc Data Sheet
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19. ABSTRACT

Computational modelling has been used successfully to explore the influence of organisation structure on organisation performance. Results from these explorations have helped to develop organisation science theories. This report describes the method and results of a series of experiments that were conducted to assess the suitability of ORGAHEAD, a computational modelling tool, in analysing operational command structures.